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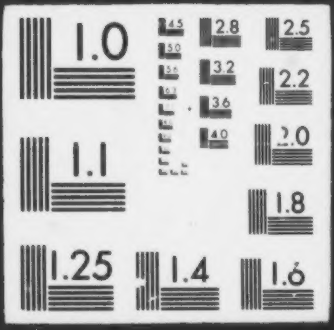
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Evaluating Transportation Controls to Reduce Motor Vehicle Emissions in Major Metropolitan Areas

Institute of Public Administration

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EVALUATING TRANSPORTATION CONTROLS TO REDUCE MOTOR VEHICLE EMISSIONS IN MAJOR METROPOLITAN AREAS

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16. Abstracts

The overall objective of the research described in this report is to evaluate transportation controls to reduce motor vehicle emissions in major metropolitan areas. The report proposed to bring together in a preliminary form, a description and evaluation of those transportation controls which could conceivably reduce motor vehicle emissions in the next few years. The information is presented, divided into seven chapters, each of which deals with a different transportation control. The chapter headings are as follows: Inspection, Maintenance and Retrofit; Gaseous Fuel Systems; Traffic Flow Techniques; By passing Thru Traffic; Improvements in Public Transportation; Motor Vehicle Restraints and Work Schedule Changes. Each chapter consists of a section defining and describing the measures considered an analysis of the air pollution control potential, and a discussion of institutional feasibility.

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PREFACE

A number of the Institute of Public Administration's staff and Consultants contributed to this study, including: John W. Hoicka; Donald Infeld; Anna Karavengelos; Sumner Myers; Gilbert Nelson; Thomas Pogue; Joseph S. Revis; Ralph E. Rechel; Lee H. Rogers; Helen Scott; Terry Trumbull; and Robert Witherspoon (Project Director). Michael Keaton was principal investigator for Teknekron, Inc. Dianny Fishman was project Administrative Officer.

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INTRODUCTION AND SUMMARY

The following final Report, prepared by the Institute of Public Administration and Teknekron, Inc., in cooperation with TRW, Inc., presents preliminary findings from research undertaken for the Office of Land Use Planning of the Environmental Protection Agency. The overall objective of the research is to evaluate transportation controls to reduce motor vehicle emissions in major metropolitan areas. Our terms of reference were to make an appreciation of transportation controls, and to assess their effectiveness in reducing emissions, their feasibility and the probable costs. We were directed to define transportation controls very broadly, but to give priority to those measures most likely to be capable of being implemented in the next few years.

Purpose and Organization

The purpose of this final Report is to bring together in a preliminary form a description and evaluation of those transportation controls which could conceivably reduce motor vehicle emissions in the next few years. In the course of our researches, we have reviewed the relevant transportation literature, as well as more recent works which specifically address the use of transportation controls to reduce motor vehicle emissions (see bibliography attached to this report). We have also attempted to summarize new evidence which is pertinent (e.g., recent research on traffic flow improvements on a network-wide basis, demonstrations to date of public transport improvements, accumulated experience with vehicle-free zones) much of which has not appeared previously in print.

Under the Clean Air Act amendments of 1970 and subsequent action by the EPA Administrator, state implementation plans for meeting national ambient air standards must be submitted to EPA by February of 1972. In many cases, meeting national ambient air standards will require transportation controls. The intent of this final Report is to provide assistance in the preparation of transportation components of state plans.

Given the scope of the study described above, it may be convenient to indicate how this final Report is organized. Briefly, it consists of an Introduction and Summary statement, followed by seven chapters, each dealing with a different transportation control. The chapters in order of presentation are: Inspection, Maintenance and Retrofit; Gaseous Fuel Systems; Traffic Flow Techniques; Bypassing Thru Traffic; Improvements in Public Transportation; Motor Vehicle Restraints and Work Schedule Changes. Each chapter consists of a section defining and describing the measures considered, an analysis of the air pollution control potential (including an estimate of the maximum feasible emission reductions which would be possible) and a discussion of institutional feasibility (including probable costs).

Study Focus and Working Assumptions

Before proceeding, the focus for the study (of which this final Report is part) as well as our working assumptions should be noted. In many cases, exclusions or simplifying assumptions have had to be made so that the subject matter left, while large and complex, is nevertheless coherent and manageable.

In order to focus the study, we have been asked to give priority to those transportation controls capable of being introduced by 1977 to reduce carbon monoxide emissions from light duty motor vehicles in and around high pollution areas of large metropolitan regions. Each of these terms of reference is taken up in turn.

Focusing upon transportation controls capable of implementation (and, by implication, impact) by 1977, it should be stressed, precludes consideration of many measures which hold out the potential for reducing emissions, but over a longer term. For example, the 1977 time frame rules out major new highway construction (e.g., circumferential routes to bypass through traffic away from central city areas), the provision of new rapid rail systems (except those already under construction, i.e., San Francisco's BART and Washington, D.C.'s Metro). The same time frame also precludes most land-use controls (e.g., modification of zoning regulations respecting new office construction so as to limit total parking space, a measure which would require at least a decade to have an appreciable impact on air quality). We have considered many of these medium and long-term controls in passing, and have attempted to draw attention to the longer run consequences, We have not been able to discuss them in detail because of the short time frame (in effect, the next five years) of this study.

Primary concern with carbon monoxide emissions, it should be emphasized, is not to the exclusion of other vehicle emissions (e.g., hydrocarbons and nitrogen oxides). Trade-offs among pollutants (e.g., the possibility that increased vehicle speeds reduce carbon monoxide but may increase nitrogen oxides) have been kept in mind throughout.

The focus of this study is on "light duty vehicles," as defined by EPA.[1] Generally stated, this category comprises commercial vehicles with a rating of up to 6,000 pounds GVW, or passenger vehicles with occupancy of up to 12 persons. Time did not permit detailed consideration of trucks, their contribution to traffic congestion and accompanying air pollution and various truck-specific transportation controls. While trucks may account for a high proportion of carbon monoxide emissions in some downtown areas (Manhattan is an extreme case), more generally they represent only a small proportion of typical traffic streams. The main problem is that the usual travel pattern of trucks, involving frequent stops and parking, tends to tie up traffic and thus compound congestion and air pollution. Among the many control possibilities that could be studied are: regular inspection and maintenance, the establishment of special truck routes, provision of improved loading facilities, and a modification of pick-up-and delivery hours.

---

[1] Federal Register, XXXVI, No. 228, Nov. 25, 1971, p. 22449. GVW refers to gross vehicle weight, meaning the manufacturer's gross weight rating for the individual vehicle. This EPA definition, it should be noted, differs from the Department of Commerce classification of light duty vehicles to encompass any vehicle with a gross vehicle weight of 10,000 pounds or less.

For this report, we have also focused on automobile air pollution problems arising primarily from travel into, out of and within central cities, and particularly the central business district (CBD)[1] during the peak or rush hours on the mornings and afternoons of workdays. In most cities these movements are apparently the greatest contributors to congestion and motor vehicle emissions. Trips at other times of the day or week can create significant air pollution problems, but these are almost always of second-order importance. Furthermore, in most cities it is apparently in these core areas (e.g., the CBD) that daytime population densities (and hence exposures to air pollution) are greatest. This generalization, however, does not hold good for metropolitan areas where highly dispersed travel patterns tend to spread motor vehicle emission relatively uniformly throughout the area. Los Angeles provides a good example.

Finally, the study concentrates on large metropolitan areas, with specific reference to six central cities: Chicago, Denver, Los Angeles, New York City, San Francisco and Washington, D.C. Illustrative data from some of these cities (and particularly Washington, D.C.) are provided in this final Report.[2] In general, however, the conclusions drawn in the present document are thought to be valid for most large metropolitan areas.

---

[1] Central cities are usually defined as those areas within the incorporated limits of the major city in any metropolitan area. Definitions of CBD's vary widely, but generally refer to the high density commercial and business cores of cities.

[2] Additional data acquisition and interviews in the field are planned for each city in subsequent stages of this study.

In addition to the above study focus, we have taken as the basis for this final Report several working assumptions. First, we were asked to assume that motor vehicle manufacturers will meet the federal new car emission standards for carbon monoxide by 1975. At this writing, however, it is by no means clear that appropriate exhaust control systems will be available to meet the deadline imposed by Congress.[1] Furthermore, even if exhaust control systems are developed by the deadline to meet new car emission standards, these systems may be highly unreliable. These inherent uncertainties as to the availability and reliability of new systems, argue strongly for contingency planning, an argument that is reinforced by other considerations. For example, it may well be that the increased cost of a vehicle arising from pollution control and safety equipment will discourage the replacement of old vehicles. Also, it should be realized that as Americans depend increasingly upon the automobile as a way of life, more and more vehicles are going to be in circulation. Many of the measures discussed in this final Report can act as useful supplements to federal new car emission standards, all the more so if enforcement of emission standards is less effective than hoped for.

---

1. In a recent study for EPA, the National Academy of Sciences reported that the requisite technology to meet clean-air requirements is lagging and suggested that the 1975-76 deadlines be extended by one year. See National Academy of Sciences, Committee on Motor Vehicle Emissions, Semi-Annual Report to the Environmental Protection Agency (Washington, D.C.: National Academy of Sciences, January 1972).

Second, we have assumed that significant reductions in person trips into and around central cities cannot be accomplished without radical changed in land-use patterns (i.e., in residential and commercial locations). To achieve these changes would take at least two to three decades.[1] In the short term, reductions in vehicle miles traveled (not person trips) may be accomplished through diversion of motor vehicle trips to public transportation.[2] However, even modest diversions would require important improvements in public transportation to enable trips to be made.

Third, we have assumed that any improvement in the comfort and convenience of trips, or a reduction in travel times, will generate additional trips which would not have been forecast as part of the long-term growth. At the present time, the precise reasons for making these additional trips are not well understood, although available evidence and the observations of experienced transportation analysts all tend to support this assumption.[3]

---

[1] Implementation of some of the transportation controls discussed in this Interim Report may have a very minor impact on land use by 1977, probably through a small redistribution of origins and destinations.

[2] Public transportation had been broadly defined for this report to include mass transit as conventionally defined (rapid rail and bus systems), as well as a number of other means of conveyance such as taxi, demand-responsive systems, car pools and people movers.

[3] For details, see Chapter 3, section on "Annual Traffic Growth." Because the dynamics of long-term and induced travel are not well understood, we have used a range of reasonable assumptions in estimating potential emission reductions, as elaborated in Appendix D.

Preliminary Conclusions

This report is the result of a six-month study of a large, complex subject. Most of the transportation controls examined have been considered only recently for purposes of air pollution control. Accordingly, conclusions can be only tentative at this stage. However, at this point in the study our main conclusions are:

1. In most of the metropolitan areas under study, overall emission reductions of at least 50 percent from existing levels appear required to meet the national ambient air standards for carbon monoxide by 1975. These required reductions are substantially higher in some central city areas (e.g., 80 percent in Midtown Manhattan).[1]

2. Measured against this scale, most transportation controls that are capable of being introduced in the next few years offer the potential for only modest reductions. Details are summarized in Table 1.

3. Even those controls which are easiest to implement will take several years to develop and put into effect. All controls would entail very substantial implementation costs (although in some cases, such as an increase in parking rates, these costs could be recouped from revenue).[2]

---

[1] Unless otherwise noted, "emissions" or "emission reductions" refer to carbon monoxide throughout this report.

[2] Preliminary cost estimates for improving public transportation are provided in the concluding section of this Introduction and Summary.

Table 1

IMPACT OF TRANSPORTATION CONTROLS ON TRAVEL PATTERNS AND MOTOR VEHICLE EMISSIONS (CARBON MONOXIDE FROM LIGHT DUTY MOTOR VEHICLES ONLY)

	Transportation Control Candidates	Impact on Travel Patterns[1]	Impact on Motor Vehicle Emissions[2]
SHORT TERM (2-5 years)	Inspection, Maintenance and Retrofit	No changes in modal mix, trip generation or origin-destination patterns.	10 to 25 percent.[3] Upper range (particularly 20 to 25 percent) decidedly less likely than lower range (particularly 10 percent).
	Gaseous Fuel Systems	No changes in modal mix, trip generation or origin-destination patterns.	Less than 15 percent.[4] Appropriate only for large, centrally-maintained fleets which account for a relatively high proportion of total vehicle miles traveled (e.g., taxicabs in Borough of Manhattan).

---

1. Transportation controls are arranged in order of increasing impact upon travel patterns, and hence upon social and economic activity and location of land use. To the extent that these impacts imply increasing social and economic dislocation, each successive transportation control would need correspondingly longer lead times to implement and take effect.

2. Expressed as percent of emissions attributable to light duty motor vehicles. Highest values are estimates of maximum feasible emission reductions, using data from central cities where control in question appears to have greatest potential for reducing emissions. It is extremely unlikely that any city could achieve maximum reduction from each of controls. Lower values do not represent minimum emission reduction, but rather an estimate based upon moderately favorable conditions. Estimates for improvements in public transportation, motor vehicle restraints and work schedule changes assume a reduction in motor vehicle miles traveled results in equivalent reduction in motor vehicle emissions. All estimates are for initial reductions and do not take into account deterioration (e.g., deterioration of control devices due to accumulation of mileage).

3. Estimates for inspection and maintenance only. See Chapter 1 and Appendix A for further discussion.

4. Estimates for simple conversion from gasoline to LPG or natural gas. See Chapter 2 and Appendix B for further discussion.

Table 1
(page 2 of 4)

IMPACT OF TRANSPORTATION CONTROLS ON TRAVEL PATTERNS AND MOTOR VEHICLE EMISSIONS (CARBON MONOXIDE FROM LIGHT DUTY MOTOR VEHICLES ONLY)

	Transportation Control Candidates	Impact on Travel Patterns	Impact on Motor Vehicle Emissions
SHORT TERM (2-5 years)	Traffic Flow Techniques	No changes in modal mix. Possible increase in trip generation as a result of improvements in traffic flow. No changes in origin-destination patterns, at least for the short term.	Less than 20 percent.[1] However, emissions appear to decrease for only the year immediately following implementation, after which time emissions may increase above original levels due to growth in traffic volumes. To control traffic volumes, motor vehicle restraints would be required.
	Bypassing Thru Traffic	No changes in modal mix. Possible increase in trip generation as a result of improvements in traffic flow. No changes in origin-destination patterns, at least for the short term.	Less than 5 percent.[2] Measures requiring new construction (e.g., circumferential routes) not implementable within five years. Modest bypassing may be possible through use of directive signs and/or signals. More substantial bypassing will require motor vehicle restraints.

---

1. Based on illustrative example assuming a 30 percent increase in network-wide average vehicle speed. See Chapter 3 and Appendices C and D for further discussion.

2. Estimates for traffic which could be bypassed away from central cities as a result of improvments capable of implementation in the short term, but in the absence of motor vehicle restraints. See Chapter 4 for further discussion.

Table 1
(page 3 of 4)

IMPACT OF TRANSPORTATION CONTROLS ON
TRAVEL PATTERNS AND MOTOR VEHICLE EMISSIONS
(CARBON MONOXIDE FROM LIGHT DUTY MOTOR VEHICLES ONLY)

	Transportation Control Candidates	Impact on Travel Patterns	Impact on Motor Vehicle Emissions
MEDIUM TERM (5-10 years)	Improvements in Public Transportation	Changes in modal mix by improvements in public transport; no change in trip generation or origin-destination patterns at least in the short term.	Less than 5 percent.[1] Improvements in public transport are a necessary but not sufficient condition for reducing motor vehicle emissions. To have an appreciable effect on emissions public transport improvements must be combined with motor vehicle restraints. Restraining or restricting motor vehicles, however, would require substantial public transport improvements to provide an alternate means of making trips.
	Motor Vehicle Restraints	Changes in modal mix by improvements in public transport and motor vehicle restraints. Only minor changes in trip generation, or origin-destination patterns at least in the short term.	5 to 25 percent.[2] Potential emission reductions depend upon the severity of restraints. Several motor vehicle restraints are administratively feasible. However, the mechanics of imposing motor vehicle restraints are much less of a problem than gaining public acceptance to limit "freedom of the road."

---

[1] Estimates for public transportation broadly defined to include mass transit (rapid rail and bus systems) as well as other means of conveyance, such as taxi, demand-responsive systems, car pools and people movers. Estimates are for reductions in traffic in the absence of motor vehicle restraints. See Chapter 5 and Appendix E for further discussion.

[2] Lower estimates are for doubling downtown parking rates. Higher estimates are for tripling or for quadrupling downtown parking rates, depending upon comprehensiveness of parking control program. See Chapter 6 and Appendix F for further discussion.

Table 1
(page 4 of 4)

IMPACT OF TRANSPORTATION CONTROLS ON TRAVEL PATTERNS AND MOTOR VEHICLE EMISSIONS (CARBON MONOXIDE FROM LIGHT DUTY MOTOR VEHICLES ONLY)

	Transportation Control Candidates	Impact on Travel Patterns	Impact on Motor Vehicle Emissions
LONG TERM (10-20 years)	Work Schedule Changes	Changes in modal mix, possible reduction in trip generation (particularly for the journey to work) and changes in origin-destination patterns due to additional recreational trips.	Less than 3 percent.[1] Work trips would be reduced but increased leisure time would probably generate additional recreational trips (although these are likely to be primarily at off-peak periods to and from areas outside the central city).
	Land Use Controls[2]	Change in modal mix; change in origin-destination patterns; change in trip generation.	Could not be implemented with any appreciable effect on emissions in the short term. Medium and long term effects not known.

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1. Estimates are for 4-day week, with working days spread over six days, assuming 30 percent of vehicle miles traveled are accounted for by the journey to work and a maximum of 25 percent of the labor force on 4-day week by 1977. See Chapter 7 for further discussion.

2. For example, public policy could encourage land use patterns which would minimize distances between home and work, home and school, and home and shops. In addition, residential and commercial development could be promoted around existing rail and bus lines (and such systems extended) so that public transport would be more accessible to a larger portion of the metropolitan population.

It should be stressed that, absent more empirical data and computer simulation, the above estimates must be considered as rough approximations only. As noted in Table 1, estimates are expressed as a percentage of carbon monoxide emissions attributable to light duty motor vehicles (see EPA definition given earlier). To the extent that carbon monoxide emissions in any area are caused by heavy duty vehicles (e.g., buses or trucks) or by stationary sources (e.g., space heating), overall emission reductions would be less than estimated here. The proportionate contribution from these sources, of course, must be determined on a city-by-city basis using an emissions inventory for each area.

As also noted in Table 1, estimates are for initial emission reductions and do not take into account deterioration of control devices due to accumulation of mileage. For reasons indicated elsewhere[1] reliable data on deterioration are not available at this time. However, using a hypothetical example, if maintained motor vehicles return to their pre-maintained emission levels within six months, the emission reduction from an annual inspection and maintenance program would be only one-half of the values estimated above.

An additional difficulty is that some transportation controls (notably motor vehicle restraints) could have additive effects by both reducing vehicle miles traveled and improving traffic flows. Even if

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1. See Chapters 1 and 2, sections on "Air Pollution Control Potential."

emissions-speed relationships were known with confidence,[1] these additive effects cannot be estimated on a network-wide basis without computer simulation.[2]

Nevertheless, it does appear that the additive effects of motor vehicle restraints would result in substantially greater emission reductions than estimated above.[3] This potential, along with the limited effectiveness of other transportation controls, indicate that vehicle restraints would be required in many major metropolitan areas (such as the six under study) to reach and maintain national ambient air standards for carbon monoxide by 1975. In addition, motor vehicle restraints would have to be accompanied by important improvements in public transport if serious social and economic repercussions are to be avoided.

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[1] Although empirical data are extremely limited, it is usually assumed that emissions (carbon monoxide and hydrocarbons) are lower in freely flowing traffic than in congested stop-and-go conditions. There is some evidence that the converse holds for nitrogen oxides (i.e., that NO_x emissions increase with higher vehicle speeds). Available research and some complicating technical considerations are treated in Appendix C to this report.

[2] Using computer simulation, controls could be tested for groups of intersections for the network as a whole, taking into account data on street geometry, vehicle speeds, turning percentages at each intersection, existing signalization and so forth.

[3] We did develop an example to illustrate this principle. Under one set of assumptions (see Appendix D, section on "Reducing Traffic Volumes with Motor Vehicle Restraints" for details), implementation of a motor vehicle restraint program capable of restraining traffic volumes on an urban arterial could reduce emissions by more than 50 percent.

Assuming substantially improved public transport, the implementation of some forms of motor vehicle restraints[1] would appear technically feasible within five years. However, the basic question these measures raise is the extent to which it is politically possible to deprive people of some of the convenience of their cars in return for cleaner air.

Furthermore, changes in prevailing travel patterns (e.g., commutation by private passenger car) and the provision of public transport cannot be brought about over night. Since the automobile is intricately related to almost all aspects of community life,[2] the social and economic consequences of changing these established relationships are likely to be profound.

We conclude that for motor vehicle restraints to be recommended, it would be desirable to consider them as more than simply short term measures for air pollution control alone.[3] Motor vehicle restraints may be warranted over a longer term[1] and on other grounds (e.g., reducing noise and relieving congestion) in addition to air pollution control. This suggests the desirability of evaluating motor vehicle restraints (as well as some of the other more promising transportation controls considered in this report) within a broader context and a longer time frame than has been the objective of this study.

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[1] For example, parking controls, toll collection, or a congestion pass approach. There is already good evidence in many European and Japanese cities that motor vehicle restraints are feasible, at least on a limited scale; these restraints have also proven highly effective in reducing localized carbon monoxide concentrations.

[2] For example, in addition to passenger movement, motor vehicles in central cities are relied upon extensively to provide for the delivery of goods, emergency services (e.g., police and fire), mail distribution and pick-up, maintenance work on public utilities and a multitude of other essential services.

[3] It should also be pointed out that, since the transportation controls discussed in this report all involve substantial implementation costs and/or significant changes in travel patterns, and can take effect only over an extended period of time, they are not appropriate for intermittent application.

In addition to the above, we have arrived at the following conclusions concerning each transportation control.

Inspection, Maintenance and Retrofit

At the present time, enforcement of federal new car emission standards is the principal public policy to control motor vehicle emissions. Its effectiveness depends upon in-use vehicle conformance (i.e., mileage accumulation without a substantial deterioration of exhaust control systems[2]). Under the Federal Clean Air Act, authority to regulate emissions from in-use motor vehicles is retained by state and local governments; however, states are required to provide for periodic inspection and testing of in-use vehicles to the extent "necessary and practicable." The same legislation also authorizes federal funding for "effective" inspection, maintenance and retrofit programs.

Preliminary indications are that regulation of in-use vehicle emissions will be necessary in several large metropolitan areas to meet national ambient air quality standards. But the practicability and effectiveness of inspection, maintenance and retrofit cannot be precisely established at this time.[1]

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[1] For example, a number of considerations noted earlier argue strongly for contingency planning in the event that efforts to control emissions at the source should fall short. Motor vehicle restraints could constitute an important component of contingency plans.

[2] The ability of auto manufacturers to assure quality control of exhaust emission control systems in assembly-line vehicles will be important so as to ensure that these do not deviate substantially from the sample vehicles tested by the Federal government.

Estimating the effectiveness over time of inspection, maintenance and retrofit is impossible at present, due to imperfect information (e.g., respecting deterioration of maintained vehicles between inspections) and inherent uncertainties (e.g., as to post-1975 exhaust control systems). Acquiring additional information will probably take another 12 to 18 months for experimentation in pilot projects. These lead times imply that most federally funded inspection, maintenance and retrofit programs will probably not be in place until at least 1975.

Absent this information, it is nevertheless possible to arrive at a rather broad range of initial emission reductions which can reasonably be expected. The most likely initial reductions from inspection and maintenance (as applied to the light duty motor vehicle population) would be on the order of 10 to 25 percent. Values in the upper range (particularly 20 or 25 percent) are decidedly less likely than those in the lower range (particularly 10 percent). Deterioration of maintained vehicles (in the

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1. Implicit in the notion of practicability are considerations as to test regimes, organizational arrangements, diagnostic information, costs, manpower requirements, and implementation times. Many of these considerations are complex and highly technical, and cannot be resolved until completion of several investigations currently being conducted under EPA sponsorship. Preliminary data are expected to be available in 1972. The major issues requiring resolution are set forth in Chapter 1, and where possible, tentative conclusions are drawn on the basis of existing evidence.

interval between inspections) would lessen the effectiveness of this control.[1]

With respect to retrofit, currently available "industry type" devices appear able to reduce emissions by 20 to 25 percent for pre-controlled vehicles. For a number of reasons, however, these reductions are much more modest when applied to the light duty vehicle population as a whole.[2] We conclude that retrofit does not warrant further consideration as a control with widespread application.

Gaseous Fuel Systems

Conversion of gasoline-powered motor vehicles to gaseous fuels (liquified petroleum gas or natural gas) should be considered only for large centrally maintained fleets which account for a high proportion of total vehicle miles traveled and operate in severely polluted areas.[3] Medallion taxicabs in the Borough of Manhattan are one such example. Emission reductions achievable through conversion to gaseous fuels are highly variable. However, for pre-1975 motor vehicles significant reductions in carbon monoxide and hydrocarbon emissions and some reduction in nitrogen oxide emissions can be expected.

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1. For example, should an inspection and maintenance program be implemented, and the average vehicle be returned to original (i.e., pre-maintained) condition after six months, the annual air pollution control potential of the program would be only half of the values indicated above.

2. For details see Chapter 1 and Appendix A.

3. For reasons discussed in Chapter 2, we have examined only simple conversion (i.e., conversion which does not include modification such as exhaust gas recirculation or the addition of thermal reactors and/or catlytic converters).

New car federal emission standards for 1975 and beyond are below levels which can be achieved through simple conversion. Consequently, conversion would be an interim measure, assuming 1975 emission standards are achieved.[1] Diversion of natural gas from power production or space heating to motor vehicle use would be counter-productive from a pollution abatement point of view.

Implementation problems loom large even for the limited case of converting fleet vehicles. Specific economic and/or regulatory incentives would be required to induce fleet owners to convert to gaseous fuels, in view of the capital investments required, the logistics of fuel supply, reduced drivability, new maintenance requirements, and the loss of manufacturers' warranties implicit in conversion.

Traffic Flow Techniques

Traffic flow techniques can be implemented to reduce congestion, thus smoothing traffic flow and increasing average vehicle speeds.[2] When carefully designed and implemented to take network repercussions into account, these techniques (e.g., improved signalization, channelization, exclusive left turn lanes and others) can have significant impacts on speed.

A review of recently available "Before" and "After" results of traffic flow experiments carried out in Louisville and Newark reveals that, of the 43 instances in which average travel speeds increased after implementation of traffic flow techniques, approximately two-thirds of the speed improvements fell between the class intervals 5-10 percent at the lower bound and 35-40 percent at the upper bound. The median speed increased from 13.6 to 17.3 mph, a 27.6 percent increase.

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[1] That is, federal new car emission standards for 1975 and after require more stringent control than appears possible with simple conversion.

[2] As noted earlier, however, there is some evidence that NO_x emissions increase with increased vehicle speeds. Consequently, consideration of traffic flow techniques requires careful evaluation of pollutant tradeoffs (e.g., less CO but more NO_x) especially in those areas (e.g., Los Angeles) where nitrogen oxides appear to be the primary problem.

Assuming an increase in average vehicle speed along an urban arterial of from 10 to 15 mph, emissions could be reduced by about 20 percent. At best, however, these emission reductions would seem short lived (no more than one year under most assumptions[1]). At worst, emissions could be significantly greater than if no "improvements" had been implemented at all.

We conclude that traffic flow techniques -- unless accompanied by motor vehicle restraints -- could well be counter-productive from an air pollution control point of view. Furthermore, many traffic flow techniques would render public transport (especially bus) less attractive relative to the automobile.[2] Finally, implementation of traffic flow improvements on a network wide basis would be a costly measure, particularly when weighted against the ephemeral effectiveness of these controls.

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[1] For details see Appendix D. Estimating emission reductions from traffic flow techniques must take into account both higher average speeds (which reduce emissions) and higher vehicle volumes (which increase emissions). Lower emissions from higher average speeds can be quickly overwhelmed by additional emissions from greater vehicular volumes (caused by normal long-term traffic growth and "induced" traffic resulting from improved conditions). To illustrate these possibilities, we developed a number of assumptions about long-term induced traffic growth. It should be emphasized, however, that increases in vehicle volumes are highly variable, depending upon existing "capacity saturation" and local travel trends.

[2] An important exception concerns bus priority systems, discussed in Chapter 5.

Bypassing Thru Traffic

In large central cities (such as the six under study) thru traffic can account for about 5 to 20 percent of total traffic volumes, even at peak hours. From an air pollution control viewpoint, bypassing thru traffic would (1) shift vehicle miles traveled away from already congested central city roadways and (2) smooth traffic flows by a separation of thru and local traffic in the areas affected. Both results would reduce emissions in high pollution areas of the central city, the first by redistributing emissions elsewhere, the second by bringing higher average vehicle speeds, fewer stops and starts and idling and the emission reductions associated with these improvements.

Several possibilities are available to bypass thru traffic, including the use of circumferential routes (e.g., beltways), inner city barriers (e.g., as in Gothenburg, Sweden), and directive signs or signals. To the extent that these measures depend upon new construction, they cannot be implemented within the next five years; to the extent that other measures (e.g., directive signs and/or signals) are used and are designed specifically to attract and divert vehicles away from central cities, some emission reduction may occur. Our best judgment is that the reductions which could be achieved in the short term (i.e., within five years) would not exceed 5 percent for most central cities. More substantial reductions would require motor vehicle restraints (e.g., through toll collection) to discourage thru trips. Given the substantial share of thru traffic in some central city areas (a third or more of total traffic is typical in the CBD), this possibility appears to merit more attention than it is now receiving.

Improvements in Public Transportation

Reducing motor vehicle emissions implies a modal diversion from private passenger cars to public transport. However, extensive review of recent experience with public transport improvements reveals that these improvements alone hold little promise for attracting motorists out of their automobiles.[1] Modal diversion to public transport, moreover, does not necessarily reduce motor vehicle traffic. Of all public transport improvements in recent years, the Philadelphia-Lindenwold line has often been cited as a great modal diversion success. However, special analysis undertaken as part of this study did not establish that any reduction in motor vehicle traffic had occurred.

We conclude that public transport improvements alone hold out little promise for major modal diversions, much less a reduction in motor vehicle emissions. Our best judgment is that even extensive

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1. There are no prospects at all for displacing motorists to public transport by minor improvements or renewal of equipment. Only an all-out marketing effort, complete with variable scheduling and great increases in express services, can even hold present levels of public transport traffic. The few public transport success stories of recent years have been carefully marketed efforts that meet specific consumer needs and operate nearly door-to-door at nearly private passenger car speeds. People have demonstrated their willingness to pay higher fares for these services.

improvements would be unlikely to reduce vehicle miles traveled[1] (and hence emissions) by more than 5 percent in any major metropolitan area.

Improvements in public transport, therefore, are a necessary but not sufficient condition for reducing motor vehicle emissions. They are necessary because reducing motor vehicle use in high pollution areas will require substantially improved public transport to provide an alternative means of making trips.[2] They are not sufficient, however, since public transport improvements, unaccompanied by motor vehicle restraints. will reduce motor vehicle traffic only modestly, if at all. Indeed, as a result of some improvements (especially rapid rail) emissions may actually increase where they are currently worst, in the downtown and other densely developed areas.[3]

Motor Vehicle Restraints

For many transportation controls (i.e., traffic flow techniques, bypassing thru traffic and improvements in public transportation) to be effective, motor vehicle restraints will be required. These restraints could consist of parking regulations or the imposition of higher parking prices, the regulation of road use (e.g., pedestrian malls or vehicle free zones) or road pricing (e.g., toll collection or the use of a congestion pass in high pollution areas). None of these measures will be politically popular, and intense opposition can be expected from those whose direct interests are involved (road users, automobile owners associations, downtown businessmen, parking garage owners and others).

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[1] Reference is to vehicle miles traveled by light duty vehicles (e.g., the private passenger car).

[2] In no U.S. metropolitan area at present is there public transport which is capable of satisfying all trip-making needs, even in the CBD. To meet these needs, expansion of existing taxi service and the introduction of demand-responsive systems (e.g., dial-a-ride) appear the most promising. Shared rides on these systems would probably not reduce work trip traffic significantly, but could cut down on the growing use of second cars.

[3] This suggests that EPA should monitor the possibility, particularly with implementation of new rapid rail systems in San Francisco and Washington, D. C.

This suggests that for motor vehicle restraints to be at all acceptable to the public (and hence workable and effective), the quality and quantity of public transport must be importantly and visibly improved. Improvements should be made in conjunction with any strategy to reduce motor vehicle use.

The most promising restraint, at least for the short term, would be to intensify control over the location, amount and use of parking space, both on- and off-street. The most desirable method of control appears to be through municipal taxation, particularly where local revenues will be required for improved and expanded public transport. The effectiveness of parking controls, however, will be limited by several factors. First, thru traffic and internal circulation will not be affected; indeed it would probably be encouraged if a lower volume of local traffic results from parking controls in some areas. Second, comprehensive parking controls, particularly over already existing space provided by private firms and government agencies, would be difficult to enforce and would probably require new legislation. In many downtown areas, such space constitutes more than half of existing storage capacity.

To the extent that it is practical, road pricing would be a more effective motor vehicle restraint for purposes of air pollution control. This potential (as well as other ancillary benefits) argues strongly for further exploration of the concept to determine whether and how such a system could be implemented. Some measures (e.g., toll collection or a congestion pass approach) show promise for near-term application, although substantial increases in enforcement may be required. The mechanics of imposing these controls, however, are less of a problem than gaining public acceptance to limit "freedom of the road" in areas of high air pollution.[1]

If motor vehicle restraints are to be effective, dramatic departures from previous practice would appear necessary (e.g., tripling or quadrupling parking rates for many areas of the city or tolling off major portions of the downtown). Restraints this severe could cause profound social, economic and land-use effects, many of which may be highly undesirable from other standpoints. For example, severe motor vehicle restraints in some areas of the central city could cause (1) employment centers to shift to the suburbs, (2) an undermining of the city property tax base, and (3) particularly adverse economic effects on low income residents.

The effectiveness of these measures, of course, will depend on the severity of restraints. Our best judgment is that the doubling of parking rates (here taken as a surrogate for motor vehicle restraints) would have little effect. However, if a comprehensive parking control program were implemented (i.e., a parking space tax of $60.00 to $80.00 per month were applied, all on-street parking were eliminated, and prohibition of illegal parking were strictly enforced), in a city such as Washington, D.C., an overall reduction in motor vehicle traffic of perhaps 20 percent, or at the most, 25 percent, might be achieved. All this assumes, of course, that public transport services would be substantially improved. In Washington, D.C., this would entail tripling or quadrupling existing rates to $90.00 to $120.00 per month for present pay parking, and imposing $60.00 to $80.00 per month rates for present free parking. These increases would appear to represent the upper limit of action at the present time.

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[1] The feasibility of these measures will vary widely in different metropolitan areas, depending on such factors as the geography of the city, the size of the central area, the availability of public transport, the shape of the street network, the urgency of the local air pollution problem, and -- probably most importantly -- the local attitudes toward air pollution control and the degree to which public officials are willing to propose politically unpalatable measures to achieve air pollution control.

Work Schedule Changes

Recent experience with work schedule changes in the United States and abroad suggest that these measures are feasible. Two measures for changing work schedules were considered: work staggering and the 4-day week.[1]

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[1] Work staggering involves making small systematic shifts in work hours of employees so that currently under-utilized travel times to the CBD are more adequately used. Conceivably, this could result in decreased peak hour congestion, and higher average vehicle speeds -- and reduced emissions. The 4-day work week has the same potential effect: since the work week is shortened, each work day will be lengthened and thus "out of phase" with traditional peak hours (at least at one of the peaks). Moreover, and much more importantly for air pollution control, the 4-day week would reduce the weekly journey to work trips of those affected by 20 percent.

Of the two measures, the 4-day week goes further towards reducing motor vehicle emissions than staggered hours because it cuts weekly commuting trips by a fifth and shifts those workers involved away from peak hour travel. The 4-day week thus combines the benefits of work staggering with an additional advantage. If this measure were introduced and working days spread over a six-day period, daily vehicle miles traveled for the journey to work could be reduced by as much as a third. Assuming 30 percent of motor vehicle miles traveled are accounted for by the journey to work[1], and 25 percent of the labor force would be on a 4-day work week by 1977, a maximum reduction of 2.5 percent in daily vehicle miles traveled could be achieved.[2] All of these assumptions, however, appear highly optimistic. Moreover, increased leisure would undoubtedly result in additional vehicle miles traveled for recreational and other trips (although these are likely to be at off-peak periods and in relatively less polluted areas).

The profound social and economic implications of a large scale shift to the 4-day week suggest that this measure should be considered from a broader perspective than congestion relief or air pollution control alone. Such an examination of the 4-day work week, although beyond the scope of the present study, should be a priority area for further research.

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1. Journey-to-work trips in a motor vehicle account for slightly less than 30 percent of total motor vehicle trips in the Los Angeles region, 26 percent in the San Francisco area and 15 percent in the Tri-State (greater New York) region.

2. (.33)(.30)(.25) = 2.5 percent

Preliminary Cost Estimates for Public Transport Improvements

Within the time available to complete this report, preparation of detailed estimates of the investment costs required to substantially improve public transportation was not possible. However, we did prepare preliminary estimates of potential investments in public transport between the period 1970-1980 to allow identification of the overall orders of magnitude implied. The estimates included a mix of short-lived, or off-the-shelf items (buses, transit cars, and so forth) and very long-lived or custom built items (new rights-of-way,including track and structures for high capacity rapid transit). The modes of transport included were bus guide-way systems, rapid transit and commuter rail. Not included were demand-responsive transit systems and generally untested technology. The estimates include substantial unmet demands (at 1971 population levels) which are expected to be fulfilled or initiated before 1980.

The basic approach was to estimate rail transit on the basis of work under way and plans in process, and bus transit on the basis of industry replacement cycles, population growth, the rate of urbanization and changes in real per capita income. These estimates do not include the scope of changes (i.e., substantial improvements in public transport services) which apparently are needed to meet national air quality standards by 1975, and in that context must be considered conservative. Table 2 summarizes the estimates for the six cities focused upon in this study.

The estimates indicate that about $13.8 billion will be required for investment if the existing plans plus some moderate improvements (such as people movers) are implemented.

Table 2

1980 INVESTMENT ESTIMATES FOR URBAN TRANSPORT
$ Millions (1971)

City	Rapid Rail	Suburban Rail	Buses	CBD People Movers	Total
New York City	2,833.1	2,223.2	587.3	250.0	5,893.6
Chicago	1,011.2	240.9	162.3	12.0	1,426.4
Washington, D. C.	2,970.0[1]	--	[2]	6.0	2,976.0
Los Angeles	2,162.3	--	[2]	24.0	2,186.3
San Francisco	427.7[3]	--	[2]	16.0	443.7
Denver	852.6	--	[2]	4.5	857.1
Total	10,256.9	2,464.1	749.6	312.5	13,783.1

1. Approximately $200 million is now under contract or in active bidding.

2. Estimates for buses are not shown except for New York and Chicago where bus investment plans were specified separately as part of comprehensive multi-modal plans. However, our estimates for bus investment needs for all metropolitan areas over 1 million population (excluding New York City, Chicago, Boston, Philadelphia and Cleveland -- all of which include buses as an integral part of multi-modal plans) amount to less than $119 million. Washington, D.C., San Francisco and Denver represent a relatively small percentage of this total.

3. This represents 30 percent of the full cost. About 70 percent is complete and 30 percent is under contract.

The estimates should be considered within the context of severe financial difficulties facing most transit systems across the United States.[1] Most systems cannot even cover operating costs, let alone finance improvements. Consequently, federal funding would be required. However, if (as provided for in The Urban Mass Transportation Assistance Act of 1970) the Federal government provided two-thirds of the $13.8 billion investment needs estimated above, over 90 percent of federal funds obligated for the entire country would be expended on just the six cities of New York, Chicago, Washington, D.C., Los Angeles, San Francisco and Denver alone. Clearly, if even modest improvements in public transport are to be made, a much greater federal commitment will be required.[2]

Operating Costs for Washington, D.C.

In addition to capital investment requirements, improved public transportation will generate increased operating costs. Again, estimates for the six cities are not possible at this point in the study. Moreover, the orders of change will of course depend on the specific operating characteristics of each city's transportation system. However, estimates have been prepared for Washington, D.C. for the year 1975. The estimates must be considered as rough orders of magnitude. The following assumptions were

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1. See Chapter 5, "Improvements in Public Transportation," section on "Institutional Feasibility."

2. It should be repeated that public transport improvements alone are a necessary but not sufficient condition for reducing motor vehicle traffic. However, if vehicle miles traveled are to be reduced by other measures, substantially improved public transport would be required to provide alternative means of making trips.

made: (1) the Metro (the new rapid rail transit under construction) will not be in operation by 1975 and all bus services will be used; (2) there would be about a 10 percent passenger diversion to bus transit by suburbanites and a somewhat smaller diversion for trip makers within the District of Columbia; (3) no cost increases would be required for off-peak service -- only for the increased demands during the peaks; (4) no change in labor practices; (5) two fare assumptions have been made -- no fare change to 1975 and a 12-15 percent increase; and, (6) only moderately improved services.

Table 3 summarizes the results of these estimates.

Table 3

BUS TRANSIT ESTIMATED REVENUES AND EXPENSES FOR
THE WASHINGTON, D.C. REGION, 1969 AND 1975

Year	Revenue ($ millions)	Cost ($ millions)	Deficit ($ millions)	Passengers (millions)	Deficit per Passenger (cents)
1969	50	58	8	150	5
1975-No Fare Change	65	80	15	186	8
1975-12-15% Fare Increase	75	80	5	186	3

Examination of Table 3 shows that the overall system deficit would be in the order of $15 million in 1975, if no fare increases were provided, and about $5 million with a fare increase of about 15 percent (about a 10¢ increase for most passengers). Thus, the deficit would increase sharply from the 1969 level without any fare changes, and probably decline slightly with a moderate fare increase. However, even a deficit of $15 million annually by 1975 would not represent an insurmountable cost obstacle (in contrast, perhaps, to the capital investment requirements) for expansion of the service needed, especially if parking taxes are imposed to restrain motor vehicle use. Revenues from such a tax would undoubtedly go a long way toward covering such deficits.

Operating Deficit for the United States

In 1970 for the United States as a whole, the total operating deficit for transit operators amounted to about $288 milion (a large part of which was accounted for in large cities such as New York, Boston, San Francisco and Philadelphia where air pollution problems are at their worst). If no improvements are made in existing public transport services, the deficit (conservatively estimated) can be expected to double by 1975 (and is probably more likely to be closer to $600 million). If major improvements were instituted, operating deficits would be even greater, particularly if fares were not increased.

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1. For further discussion of operating deficits and several proposals currently under consideration for federal assistance, see Chapter 5, "Improvements in Public Transportation," section on "Institutional Feasibility."

CHAPTER 1

INSPECTION, MAINTENANCE AND RETROFIT

Definition of Terms

Broadly defined, the programs discussed in this chapter all involve (1) the inspection of in-use vehicles, (2) the identification of high emitters (and, hopefully, the provision of diagnostic information), and (3) some requirement for subsequent corrective action (whether at inspection stations or garages). Conceivably, some corrective actions could be required without inspection. For example, spark plugs or breaker points could be replaced on the basis of their expected life. Corrective action might also be required on the basis of records kept for the federal new car warranty program.[1] Nevertheless, inspection appears to be a necessary prerequisite to corrective action for in-use vehicles on two counts: (1) to determine what corrective action needs to be taken, and (2) to reduce possible underservicing or overservicing. For these reasons, we assume that inspection should be an integral part of any effective program involving maintenance or retrofit.[2]

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1. The current maintenance procedure for one major motor vehicle manufacturer (General Motors) requires periodic servicing of vehicles by motorists. A maintenance schedule is specified at the time of purchase, and must be complied with and documented to assure continuing coverage under the warranty. Conceivably, this documentation could be the basis for requiring corrective action by motorists and/or manufacturers.

2. In this regard, one public opinion survey showed considerable apprehension about the potential abuses of emission inspection programs conducted by private garages. Northrop Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report, Volume I: Summary (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971), p. 3-1.

Maintenance Procedures

A number of maintenance procedures have been proposed for the control of carbon monoxide and hydrocarbons as summarized in Table 1-1.

Retrofit Systems

Exhaust control systems for retrofit on most pre-1968 cars[1] have been developed by various auto manufacturers and generally follow a somewhat similar approach (combining modifications and adjustments to the carburetor, the distributor and vacuum advance and installation of a retrofit device.) Existing retrofit systems can be installed relatively rapidly at local service stations.[2]

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1. Depending upon factors such as age and degree of maintenance, these vehicles may emit many times more pollution than new models. Pre-1968 vehicles are being phased out of use at a national rate of approximately 10 percent per year, but will continue to contribute disproportionately to motor vehicle air pollution for the next few years unless control devices are developed and applied. This disproportionate contribution could be even greater if substantial price increases are required for newer vehicles having emission control and safety equipment, with the result that the phase-out of older vehicles is slowed.

2. "Industry-type" retrofit devices involve manipulation of the spark advances and adjustment of the air-fuel ratio. Other, more sophisticated devices (e.g., catalytic converters,thermal reactors and exhaust gas recirculation) are currently under investigation by EPA. Such devices may be particularly effective for reducing nitrogen oxide emissions and, consequently, may have applicability through the 1972 model year (after which nitrogen oxide controls are required nationally). A comprehensive survey of most reasonably practicable retrofit devices is currently being conducted by Olson Laboratories for EPA. See, Olson Laboratories in association with Northrop Corporation, "Analysis of Effectiveness and Costs of Retrofit Emissions Control Systems for Used Motor Vehicles," prepared for the U.S. Environmental Protection Agency, December 1971. (Mimeographed draft.)

Table 1-1

INSPECTION AND/OR MAINTENANCE PROCEDURES

Procedure	Description
Visual Inspection	Check to see if control devices or systems are operative. Note any visible emissions.[1]
Minor Tune-up Requirement	Check adjustments of idle speed, air-fuel ratio, and spark advance, resetting these to manufacturers specifications.
Major Tune-up Requirement	Replace spark plugs and breaker points on basis of expected life. Possibly replace other parts of engine. Would also include adjustments of minor tune-up program above.
Exhaust Measurement at Idle	Identify high emitting engines through exhaust measurement while the engine is in idle operating mode.
Exhaust Measurement under Load	Identify high emitting engines through exhaust gas measurement while engine is inertially loaded by use of a dynamometer.[2]
Exhaust Measurements under Load for Purposes of Diagnosis	Same as above, but includes techniques to indicate the kinds of adjustments or repairs necessary.

Source: Adapted from U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emissions from Mobile Sources (Washington, D. C.: Government Printing Office, March 1970), Chapter 4.

1. Although this category is included for comprehensiveness, its practicability and effectiveness are open to serious question. For one thing, exhaust control systems are increasingly being built with modifications which are difficult to inspect visually (e.g., carburetor adjustments). Second, and contrary to conventional wisdom, visual inspection usually involves more muscular fatigue (e.g., opening and closing hoods for hundreds of vehicles) than other inspection procedures. And finally, visual inspections tend to be highly subjective.

2. Realistic emission tests may require exercising the engine under stress (i.e., "loading") in order to simulate actual driving conditions.

Air Pollution Control Potential

Federal air pollution control legislation contains two provisions pertaining to inspection, maintenance and retrofit. Section 110 (a)(2)(G) of the Clean Air Act as amended, indicates that state air pollution implementation plans must provide "to the extent necessary and practicable, for periodic inspection and testing of motor vehicles to enforce compliance with applicable standards. . ." (Emphasis added.)[1] Section 210 of the same legislation provides that "the Administrator is authorized to make grants to appropriate State Agencies in an amount to two-thirds of the cost of developing and maintaining effective vehicle emission devices and systems inspection and emission testing and control programs. . ." (Emphasis added.) In this enabling legislation, the key words respecting inspection, maintenance and retrofit appear to be "necessary," "practicable" and "effective," each of which is taken up below.

Necessary

For an inspection program (and maintenance and retrofit) to be deemed necessary implies a determination (presumably on the part of state and local air pollution officials and EPA regional representatives) that the seriousness of motor vehicle air pollution warrants corrective action. Such a determination as to necessity should be a function of ambient air

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1. A review of the Clean Air Act's legislative history does not reveal exactly what was meant by "applicable emission standards." This phrase could refer to federal new car emission standards for post-1967 vehicles, to in-use vehicle emission standards established by a state or locality, or both.

quality (and particularly motor vehicle emissions) in any given area. In many states, emission inspection programs may be only necessary for major metropolitan areas, if at all.

Practicable

Implicit in the notion of practicability are considerations as to test regime, organizational arrangements, diagnostic information, costs, manpower requirements and implementation times.

Test regime. For inspection, maintenance and retrofit to be considered practicable implies an emissions test which is quick, cheap and accurate. Such a test requires both a method for exercising the motor vehicle[1] and available instrumentation for measuring the resulting emissions. Exercising the motor vehicle can be accomplished under various test routines or driving cycles, which run a motor vehicle through a specified sequence of operating modes (e.g., idle, acceleration, deceleration, cruise). Cycles can vary according to the number of modes examined, the specific sequence of modes, the time spent in each mode, the rate of acceleration and deceleration, and the maximum speeds achieved.

Differing test cycles result in differing emissions, differences which are often substantial. Ideally, test cycles should be comprehensive so as to reflect closely the typical driving patterns observed within a specific area. Test cycles should also correlate acceptably with the full federal certification procedure. However, practical requirements (i.e., for a quick and cheap test) preclude a lengthy simulation of actual driving conditions or the full federal test.[1]

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[1] Except, of course, in the case of the idle test.

Choosing a test cycle for emission inspection programs is the key decision to be made in designing a program. Various tests and test cycles measure differing amounts of emissions, provide differing degrees of diagnostic information, and hence have differing emission reduction potentials. They also imply differing costs, facility and manpower requirements, implementation times and organizational arrangements for administering the program. The major tests and test cycles currently under study for EPA and other air pollution control agencies are indicated in Table 1-2.

Decisions as to which tests or test cycles are practicable in the sense intended by the Clean Air Act are yet to be made. The issues are complex, highly technical, and cannot be resolved until completion of several investigations currently being conducted under EPA sponsorship.

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1. Motor vehicle emission tests can be conducted for any of three objectives: (1) to certify a new car as meeting the existing emission standards (the so-called full federal certification procedure); (2) to ensure quality control at the end of the assembly line; and (3) to determine if in-use vehicles are releasing "excessive" emissions. In the present discussion, concern is primarily with tests for this last purpose, which does not require precise measurement of absolute emissions as per the full federal certification procedure. Consequently, we do not consider the full federal certification procedure (which presently requires a 12-hour "soak", followed by a 23-minute test) except to note that an acceptable correlation should exist -- at least on a pass/fail basis -- between the full federal certification procedure and the inspection of in-use motor vehicles for maintenance and retrofit purposes.

Table 1-2

TEST REGIMES

Test Category	Description
1. Idle	Unloaded test in which exhaust emission measurement is taken only while engine is in idle mode.
2. Steady State	Loaded test[1] in which exhaust emission measurement is taken at idle and at one or various cruise speeds. No measurement of transient modes (i.e., during change from one mode to another). Typical example: key-mode test.
3. Transient Mode	Loaded test[2] in which exhaust emission measurement is taken during idle, accelerations, various cruise speeds, and decelerations. Typical examples: ACID test, 7 mode-7 cycle test.
4. Diagnostic	Loaded test using sophisticated instrumentation to measure both exhaust emissions and performance of specific engine components. Test operates on a pass/fail basis by specifying performance parameters for various specific engine components (e.g., an oscilliscope can be used to determine if ignition system is performing according to manufacturer specifications). Of primary use in identifying those repairs or adjustments needed to reduce emissions.

Source: Adapted from U.S. Department of Health, Education and Welfare, National Air Pollution Control Administration, Control Techniques for Carbon Monoxide, Nitrogen Oxide, and Hydrocarbon Emissions from Mobile Sources (Washington, D. C.: Government Printing Office, March 1970). Chapter 4.

[1] The loaded test of the Steady State category is based on a road loading factor which simulates the internal friction within the vehicle due to moving parts and the air friction which occurs as the vehicle is in motion.

[2] The loaded test of the Transient Mode category is based on the road loading factor used in the Steady State category, and an inertial load factor which simulates the weight of the vehicle. This latter factor is only important during accelerations and decelerations.

Data on which to base these decisions are expected to be forthcoming in early 1972. Important issues to be resolved at that time respecting each test or test cycle, include: (1) its ability to identify high emitters; (2) its accuracy, both with respect to local driving conditions and the full federal certification procedure; and (3) its ability to yield diagnostic information as to the source(s) of excessive emissions and the adjustments or repairs which would be required.

Organizational arrangements. Closely connected with the above considerations as to test regime are questions of organization and administration. Obviously, the practicability of any emission inspection program will depend importantly upon the organizational arrangements for administering inspections. The three major organizational alternatives for emission inspection programs are summarized in Table 1-3.

Of the three major organizational arrangements identified in Table 1-3 for administrating inspection programs, the state-owned and operated alternative[1] appears the most practical for two reasons. First, state-owned and operated facilities have much higher motor vehicle inspection capacities

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[1] Although Table 1-3 summarizes the organizational alternatives at a state level, emission inspection programs could conceivably be owned and operated by local governments (e.g., counties, municipalities). Since the scope of motor vehicle air pollution in many areas may coincide more closely with local boundaries than with state borders, local government participation may be appropriate, although, as we note below, this would pose institutional problems for multi-county, bi-state or tri-state metropolitan areas.

Table 1-3

ORGANIZATIONAL ARRANGEMENTS FOR ADMINISTERING INSPECTION PROGRAMS

Organizational Arrangements	Administrative Implications
1. State Owned and Operated	State acquires necessary sites, constructs inspection facilities, equips lanes, staffs facilities and manages total program.
2. Privately Owned and Operated	State selects private contractor to manage overall program, including site selection and construction of inspection facilities. Actual ownership and operation in private sector subject to applicable state regulations.
3. State Licensing of Existing Privately Owned Facilities	State qualifies and certifies existing vehicle maintenance centers to perform vehicle emission inspection. State provides total program administration and management.

Source: Adapted from Northrop, Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report, Volume I: Summary (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971). Another arrangement for inspection of in-use vehicles would be through spot checks whereby state officials with mobile equipment would move about a given area and temporarily locate along major thoroughfares, selecting vehicles for tests at random. However, all available research indicates that the effectiveness of maintenance depends upon the proportion of the total vehicle fleet inspected. Consequently, inspection programs which check only a small proportion of the total vehicle fleet have resulted in correspondingly small emission reductions. It is conceivable that an approach combining spot inspections with strong incentives (e.g., heavy fines) could motivate the majority of motorists to maintain their vehicles in conformance with emission standards, although there has been no experience to date with this approach.

(on the order of 50,000 vehicles per station per year) than do individual service stations, either under state management or under state regulation. Individual service stations probably have average throughputs of approximately 800 vehicles per station per year.[1] These figures, in turn, imply higher overall efficiency (and hence lower per vehicle costs) for state-owned and operated emission inspection programs. Second, state-owned and operated inspection programs entail a separation of the functions of inspection and repair. This division of labor by function can be important in reducing over-servicing and is a highly desirable aspect of emission inspection programs, according to available public opinion surveys.[2]

If state-owned and operated facilities are the most appropriate for emission inspections, only three jurisdictions would be able to build upon existing safety inspection programs. Currently, 32 states (including the District of Columbia) do have periodic motor vehicle safety inspection programs. Of these, however, 29 operate under a state-appointed system, with only three (Delaware, New Jersey and the District of Columbia) having state-owned and operated inspection facilities.

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[1] These figures are for safety inspection programs in New Jersey (state owned and operated) and North Carolina (private sector). The figure for state facilities is probably an average which more closely approximates single lane stations than multi-lane facilities. New Jersey has some multi-lane facilities, but most are single lane stations.

[2] Northrop Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report, Volume I: Summary (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971), p. 3-1.

Diagnostic information. Vehicles may generate "excessive" emissions because of deterioration, maladjustment or malfunction.[1] Assuming high-emitters can be identified, the degree to which a test or test-cycle can isolate the cause of excessive emissions will determine its potential efficacy for subsequent corrective action. Furthermore, accurate diagnostic information can reduce both over-servicing and under-servicing. Diagnostic information appears especially important at the inception of inspection programs, when most mechanics have little or no experience with maintenance and retrofit for reducing emissions.[2]

Costs. A central consideration as to the practicability of the tests and test cycles concerns costs. There are many cost components of any inspection program, including program start-up costs, construction costs, operating and maintenance costs, costs to motorists for repairs (including inconvenience),[1] and so forth. A discussion of these costs is unnecessary for present purposes, although cost estimates for inspection, maintenance and retrofit are available from various reports.[2] Nevertheless, it appears that the following qualitative conclusions can be drawn:

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[1] "Excessive" is enclosed in quotation marks so as to emphasize that emission standards for in-use vehicles in most jurisdictions remain to be established, either in enabling legislation or by administrative order.

[2] In addition to the above, diagnostic information could contribute to the federal warranty program. Section 207(b) of the Clean Air Act Amendments of 1970 states that "at such time as he [the EPA Administrator] determines that inspection facilities or equipment are available" to perform emission inspections, he must require manufacturers to warranty emission control systems for five years, or 50,000 miles, whichever comes first. This strong performance warranty will replace the relatively weak defect warranty which is currently in force and should contribute importantly to enforcing upon manufacturers the responsibility for providing reliable emission control systems.

A central determination in judging liability will be whether the motor vehicle was operated in accordance with manufacturer specifications. If an emission inspection program yields sufficient diagnostic information to allow this determination, the warranty provision may be substantially strengthened. Whether, in fact, federally funded inspection programs should be used for this purpose is a major policy issue.

> 1. Large vehicle throughputs at state-owned and operated facilities, along with avoidance of taxes and the need for private sector profits, seem to permit significantly lower per vehicle testing costs than for either of the other two organizational alternatives. Per vehicle capital equipment costs would

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[1] Costs to motorists should be calculated on a net basis since some corrective actions (e.g., maintenance) may entail ancillary benefits to motorists (e.g., decreased fuel consumption). On the other hand, other corrective actions (e.g., retrofit) may have the opposite effect. Early reports from one manufacturer indicated that of 59 cars equipped with retrofit systems, 12 were made less drivable by the installation of the retrofit system, and 35 cars remained unchanged. (General Motors Corporation, The General Motors Used Car Emission Control System, December 1969).

The adverse effects of retrofit systems may include rough operation at low speeds, rough idling speed, and an increase in creep speed. It is perhaps for this reason that motorists appear reluctant to purchase a retrofit system, at least according to initial evidence. For example, an intensely promoted two-month marketing test recently conducted in Phoenix by General Motors revealed that only 528 of a possible 334,000 pre-1968 motor vehicles were equipped with retrofit (at a cost of $20 per vehicle). Ideas, Newsletter of International Research and Technology, August 1970, p. 67.

[2] See, for example, Northrop Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report, Volume I: Summary (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971), Chapter 8.

be substantially lower in state-owned and operated systems, again because of substantially larger inspection program capacities.[1]

2. Should testing under load be required (with the resulting requirement for dynamometers), state-owned and operated inspection programs appear to be the only feasible alternative. Large capital outlays required for acquisition of expensive equipment, plus the apparent need for the training and staffing of professional personnel, appear to preclude private sector operation of inspection programs with loaded testing (i.e., those involving dynamometers). It seems reasonable to assume that most service stations would be unwilling to invest more than perhaps $2,000 for capital equipment in order to be involved in an emission inspection program.

Manpower Requirements. The skill required of personnel to conduct emission tests varies considerably with the sophistication of the inspection procedure. The idle test procedure, which consists of inserting a sampling probe in the vehicle's exhaust pipe and noting the metered reading, requires little training. More sophisticated inspection procedures, especially loaded ones, require personnel with additional training. Indicative of the relative training requirements, one study concluded the idle test would require approximately 87 classroom hours of training; the key mode, 142; and the diagnostic test, 174.[2] The availability of trained manpower need not be a binding constraint on the implementation of an inspection program, however, since the time required for facility construction or modification will be sufficient to train the required manpower, regardless of cycle.[1]

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[1] This ignores, of course, the cost of drivers' time (which is probably greater in large public stations).

[2] See, Northrop Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report, Volume VI (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971), p. 2. These numbers, in an absolute sense, are somewhat speculative, and, indeed, appear high for the idle and key-mode tests. More reliable estimates will be forthcoming at the conclusion of studies to determine the present capabilities of auto mechanics in this area.

Implementation time. The time required to physically implement a state-wide emission inspection program (whether of the state-owned and operated, the state-regulated, or the private sector variety) is probably small (on the order of six months to one year). This "physical implementation time" would include the time required for construction facilities, acquiring staff and training professional personnel, and would of course depend to some degree upon the testing procedure selected. However, the "real implementation time," to include total elapsed time from consideration of program initiation by the policy-makers until actual program operation will probably be considerably longer, among other things because of the political problems involved (i.e., resistance to programs on the part of strong rural interests in some state legislatures, opposition from automobile owners associations, and so forth).

Effective

Assuming inspection, maintenance and retrofit are necessary and practical, the Clean Air Act requires that federally funded programs be demonstrated to be effective. Demonstrating pollution control effectiveness entails measuring the emission reductions achieved by maintenance and retrofit.

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1. In early 1971 it was announced that the Federal Government, under the Manpower Development and Training Act, would establish a $1,000,000 training program for mechanics, focusing on effective control of exhaust fumes and unburned hydrocarbons. The program is administered out of the Department of Health, Education and Welfare in cooperation with EPA's Office of Air Programs and major automobile manufacturers.

For any area's vehicle population, the potential emission reductions consist of both the initial reduction (achieved at the time of maintenance and retrofit) and the reduction over time (and, more specifically, the deterioration rate of maintenance and retrofit).[1] The potential for initial emission reductions will depend upon the accuracy of the test procedure,[2] and the level at which emission standards are set (which in turn determines the test rejection rate).[3] Preliminary indications concerning rejection rates seem to indicate that for most states these rates should not exceed 20 to 40 percent so as to prevent a critical overload of commercial repair facilities and to eliminate heavy burdens on the inspection program which occur because of demands for retest.[4] The probability of adverse public reaction to high rejection rates should also be a central consideration when inspection programs are developed.

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[1] Actual on-the-road reductions are significantly less than initial reductions due to the deterioration of emission control equipment efficiency with accumulated mileage (referred to here as the reduction "over time").

[2] Accuracy, of course, depends on which test or test cycle is chosen, ranging from visual inspection for the presence of control devices to exhaust measurement under load on a dynamometer to diagnose the cause of high emission and to indicate what corrective action should be taken.

[3] Other factors affecting the potential for initial emission reductions include the maintenance skills of mechanics, the age distribution of vehicles, and the degree of voluntary maintenance.

[4] Ernst and Ernst, A Study of Selected Hydrocarbon Emission Controls, Report to the U.S. Department of Health, Education and Welfare, July, 1969, and Marion F. Chew, Auto Smog Inspection at Idle Only, Report for the Society of Automotive Engineers, No. 690505, 1969.

Unfortunately, present knowledge does not permit a determination of the deterioration rates of maintenance and retrofit. Deterioration over time will depend upon a number of unknowns, such as the reliability of post-1971 emission control systems (not to mention the uncertainty attached to post-1975 emission control systems, with potentially more sophisticated technology). Differing deterioration rates for inspection and maintenance are shown in Figure 1-1. As indicated, an initial emission reduction (from e_3 to e_1) is achieved at the time of inspection and maintenance (t_1). Reductions over time depend upon the slope of the deterioration curve. Assuming an early substantial deterioration (curve d), fully half of the initial reduction would be dissipated within two months; assuming linear deterioration (curve d^1) the same initial reduction would return to half its pre-maintained level within six months; assuming late substantial deterioration (curve d^2) half of the initial reduction would disappear after nine months.[1]

Differing deterioration rates, in turn, require differing intervals between inspections. If, for example, initial reductions are dissipated rapidly, frequent inspection would be necessary to maintain vehicles below a given level (say, an emission standard for in-use vehicles). Assuming a target emission level at e_2, as illustrated in Figure 1-1, the appropriate interval between inspections would be determined by that point in time (i.e., t_2) at which emissions returned to the target level. Whether the time to t_2 is two months (t_1-t_2'), six months (t_1-t_2"), or nine months (t_1-t_2"') has an obvious bearing on the costs and feasibility of any exhaust emissions inspection program.

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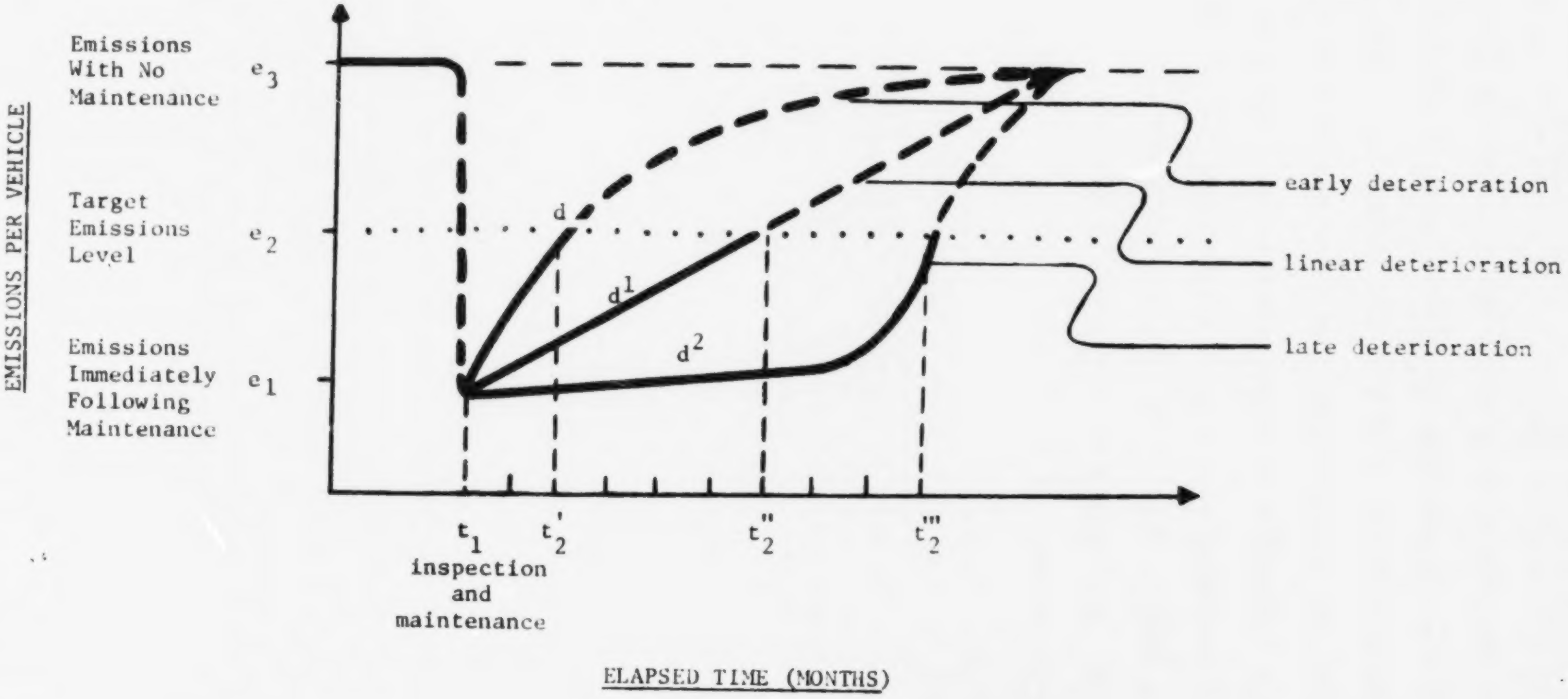
[1] These deterioration curves and time periods, it should be stressed, are solely for purposes of illustration. Further empirical research is required to determine actual deterioration rates over time.

Figure 1-1

HYPOTHETICAL DETERIORATION RATES FOR INSPECTION AND MAINTENANCE



In sum, the slope of deterioration curves for maintenance and retrofit (that is, the dynamics of deterioration over time) is so highly uncertain that, absent valid empirical data,[1] it is impossible to draw definitive conclusions at this time. Arriving at these conclusions will require an analysis of findings from pilot programs (probably of 12- to 18-month duration), some of which will probably be initiated by EPA in 1972. As data are accumulated, the effectiveness over time of inspection, maintenance and retrofit (and the costs of alternative procedures) can begin to be established.[2]

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[1] A number of empirical studies are available but are of questionable validity for any of the following reasons: (1) reliance upon testing methods which do not correlate with the full federal certification procedure (i.e., measurement of mass emissions); (2) continual changes in motor vehicle characteristics; and (3) difficulties in conducting controlled experiments. In the latter connection, for example, the so-called California study (Arthur J. Hocker, "Exhaust Emissions from Privately Owned 1966-1970 California Automobiles: A Statistical Evaluation of Surveillance Data," (Los Angeles: California Air Resources Laboratory, July 15, 1971)) provides deterioration data which enable estimations of present and projected pollution levels. Although sufficient for the state's purposes, the study does not distinguish between deterioration rates for (1) vehicles maintained on a mandatory basis (e.g., as would be required under an inspection-maintenance program) and (2) vehicles maintained on a complaint basis (e.g., maintenance only when non-function occurs). Nor does the study distinguish by place of maintenance. Such distinctions, of course, are required if the effectiveness over time of mandatory maintenance for a given area's vehicle population is to be determined.

[2] At such time, these data should in turn be compared with ambient air quality data so as to arrive at a more conclusive determination as to the necessity of inspection, maintenance and retrofit, both on a state-wide basis and for major metropolitan areas. In the final analysis, the desirability of inspection, maintenance and retrofit will be a function of ambient air quality for any given area as weighed against the practicality and effectiveness of corrective action, as determined by studies now under way or shortly to be initiated.

Absent this information, it is nevertheless possible to arrive at a rather broad range of initial emission reductions (i.e., prior to deterioration over time) which can be reasonably expected from inspection, maintenance and retrofit.[1]

Maximum Feasible Emission Reduction

Inspection and Maintenance

On the basis of research performed by TRW, Inc.,[2] Northrop Corporation,[3] and the State of New Jersey,[4] as well as information from EPA officials in the Bureau of Mobile Source Pollution Control, it appears that the most likely initial reduction in aggregate carbon monoxide emissions[5] would be on the order of 10 to 25 percent. However, it appears that values in the upper range (particularly 20 to 25 percent) are decidedly less likely than those in the lower range (particularly 10 percent).

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[1] Since the initial emission reduction potential of inspection, maintenance and retrofit depends upon a number of variables (e.g., accuracy of test procedure, test rejection rate, skill of mechanics in maintenance and installation of retrofit systems, age distribution of vehicles for any given area), it is not possible to state a single generalized value for this control.

[2] TRW Systems Group, "Emission Factors for Motor Vehicles" (internal documentation: McLean, Va.: TRW Systems Group, TRW, Inc. October 21, 1971). (Mimeographed.)

[3] Northrop Corporation, Mandatory Vehicle Emission Inspection and Maintenance, Final Report, Vol. I: Summary (Anaheim, Calif.: Northrop Corp. in Association with Olson Laboratories, Inc., 1971).

[4] New Jersey Department of Environmental Protection, Bureau of Air Pollution Control, Motor Vehicle Tune-up at Idle -- The New Jersey REPAIR Project (Trenton, New Jersey: New Jersey Department of Environmental Protection).

[5] By "aggregate" we mean the carbon monoxide attributable to light duty motor vehicles in any given area. See Appendix A. To the extent that other motor vehicles (e.g., trucks or buses) or stationary sources (e.g., space heating) contribute importantly to an area's emissions, the reductions possible from inspection and maintenance would be less than estimated here.

It should be stressed that these values represent a definite upper bound for the air pollution control potential of inspection and maintenance, since subsequent deterioration of maintained vehicles (in the interval between inspections) would lessen the effectiveness of this control. For example, assuming an initial reduction of 10 percent and deterioration to original (i.e., pre-maintained) conditions after six months, the aggregate emission reduction, when averaged over a year's period, would amount to only 5 percent. Similarly, if "complete" deterioration occurred after nine months, an annual aggregate emission reduction of only 7.5 percent would be achieved. Actual emission reductions, achievable from inspection and maintenance may also be overstated due to difficulties in (1) obtaining complete compliance from all in-use vehicle owners, and (2) securing governmental cooperation in multi-jurisdictional metropolitan areas (see below).

Retrofit

Based upon preliminary results from on-going EPA research it appears that currently available "industry-type" retrofit devices will reduce carbon monoxide emissions by 20 to 25 percent for pre-controlled vehicles.[1] Aggregate emission reductions, therefore, depend upon any area's proportion of pre-controlled vehicles and their associated vehicle miles traveled (bearing in mind that older cars are driven less than newer cars).

Assuming at least three years would be required for enabling legislation and the certification and installation of equipment, it appears the earliest date for completion of a retrofit program would be 1975.[2] With this assumption, and using vehicle age distribution and vehicle miles of travel by age data, the upper bound of possible carbon monoxide reductions can be readily calculated for any area.

A methodology for estimating potential emission reductions, as well as the assumptions we have used, is indicated in Appendix A. In California where pre-controlled cars (pre-1966) will account for only approximately 8 percent of the total miles driven in 1975, a 25 percent emission reduction for pre-controlled vehicles would achieve an aggregate reduction of 2.9 percent. Continuing the California example, pre-controlled cars will account for approximately 3 percent of the total miles driven in 1977, where 25 percent emission reduction for pre-controlled vehicles would result in an aggregate reduction of only 1.3 percent.

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[1] Recently acquired data about these devices are still being analyzed by EPA, but seem unlikely to show carbon monoxide emissions of more than 25 percent. Accordingly, and since already analyzed data indicate average reductions on the order of 20 to 22 percent, we will use 25 percent as an upper bound in the following analysis.

[2] Even this completion date may be optimistic in view of delays due to manufacturing start-up and installation in available facilties.

For the nation as a whole, pre-controlled vehicles (pre-1968) will account for approximately 17 percent of the vehicle miles traveled in 1975 (see Appendix A for details), at which time a 25 percent reductions for these vehicles would yield an aggregate reduction in carbon monoxide of 5.7 percent. Pre-controlled vehicles will account for approximately 8 percent of total vehicle miles traveled in 1977; a 25 percent reduction for these vehicles in that year would reduce aggregate emissions by only 3.2 percent. Allowing for slight variations in the age distribution of vehicles and vehicle miles traveled, a similar aggregate carbon monoxide emission reduction with retrofit would probably result for most American metropolitan areas.[1]

For at least three reasons however, the above numbers probably overstate the emission reduction from retrofit which would actually be achieved. First, the above analysis considered only initial reductions following retrofit, with no provision made for deterioration over time. Data are not currently available to estimate this deterioration exactly but it is clear that some lessened effectiveness of retrofit devices will occur, either from component failure or improper maintenance. Second, it would be extremely difficult to obtain 100 percent compliance from all in-use vehicles, as assumed in the above analysis.[2] Third, complete cooperation among neighboring governments -- an unlikely possibility -- would be required for retrofit programs in multi-jurisdiction metropolitan areas. In the Washington, D. C. metropolitan area, for instance, approximately half of the motor vehicle trips probably originate outside the District's boundaries (i.e., from Maryland or Virginia). Accordingly, an area-wide retrofit program would require cooperation from these neighboring states, or at a minimum the counties adjoining the District of Columbia.

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[1] For Washington, D. C., pre-controlled vehicles (pre-1968) will account for approximately 11.2 percent of vehicle miles traveled in 1975; a carbon monoxide reduction factor of 25 percent would reduce aggregate emissions by about 5.4 percent. In 1977 the figures are 5.7 percent of vehicle miles traveled and an aggregate emission reduction of only 2.9 percent.

[2] In addition to the costs involved for owners, retrofit systems reduce the driveability of the vehicle, and hence may encourage drivers to disconnect the devices whenever possible.

Finally, it does not appear that retrofit holds out promise for emission reductions over and above those which could be achieved from maintenance alone, maintenance which would be required if retrofit were to be introduced. Installation of retrofit requires the adjustment of several engine parameters[1] much in the way that carbon monoxide "tuning" adjustments are made for emissions maintenance.

Given the extremely modest reduction potential of retrofit, we conclude that this control does not warrant further examination. The possibility of new, more effective technology may, of course, alter the situation. As mentioned earlier, other more sophisticated technology (e.g., catalytic converters, thermal reactors and exhaust gas recirculation) is currently being tested and may hold out more promise, particularly if it is applicable to controlled vehicles as well.

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[1] The procedure for one manufacturer (General Motors) is to set the engine idle to the prescribed RPM level, tune the air-fuel mixture to a leaner (14:1 air-fuel) ratio, disconnect the vacuum advance and install a device which monitors coolant temperature and restores vacuum advance should engine temperatures reach a certain level.

Institutional Feasibility

The implementation of inspection, maintenance and retrofit will require resolution at all levels of government of a number of issues, many of which, as earlier indicated, require careful consideration of complex technical considerations. Here we attempt only to sketch out some of the most salient additional issues, many of which will require basic policy decisions on the part of the Federal Government in general and EPA in particular.

Emission and Safety Inspection Programs

The practicality and effectiveness of emission inspection programs may hinge upon whether such programs can be implemented as "add-ons" to existing safety inspection programs, or whether emission inspection programs must be implemented (and hence justified on cost-effectiveness grounds) entirely on their own.[1] In the former case, high level consultation among EPA and DOT officials presumably would be desirable so as to formulate a coordinated federal policy respecting inspection programs both for safety and emission checking.

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[1] As noted earlier, only three jurisdictions (Delaware, New Jersey and the District of Columbia) have existing state-owned and operated safety inspection programs. Of these, New Jersey is the only state that requires inspection for exhaust emissions. California has a motor vehicle inspection program for exhaust emissions at present, but it is a roadside spot check system for 1966 or newer vehicles only.

Federal Funding

Assuming a demonstration of necessity, practicability and effectiveness of inspection, maintenance and retrofit, EPA presumably would wish to make available federal funding for states (and possibly through these states, to localities). Since the cost of emission inspection programs would appear to be substantial [1] such a determination by EPA would undoubtedly entail a request to Congress for substantial additional appropriations.

Political Opposition

States (and specifically governors and state legislatures) will need to consider carefully the political advisability of proceeding with the establishment of an emission inspection program. Present evidence is fragmentary but seems to suggest that considerable political obstacles may arise. Chief executives in some jurisdictions, for example, have attempted for many years to initiate state safety inspection programs, only to be frustrated by strong rural interests in state legislatures. Indicative of these difficulties is the fact that in New Jersey, a few months ago, letters to the State Air Pollution Control Agency were running twenty to one against the proposed emission inspection program. Contrarily, in California, where motor air pollution has been perceived as a

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1. Initial investment costs for a state-owned and operated network of vehicle inspection centers in California are estimated to be approximately $12 million for idle, $19 million for key-mode and $88 million for the diagnostic test routine. Northrop Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971), p. VIII-1.

large problem for sometime, 75 percent of motorists seem to support a state emission inspection program (coupled with mandatory maintenance), according to a recent survey.[1] Little can be said conclusively at this point, but it appears that there will be substantial opposition from many special interest groups (e.g., automobile owners associations, advocates of highway construction, and so forth) to any program which would require emission inspection on a regular basis.

Local Legal Authority

At the local level, similar issues of possible political opposition will arise, should the chief executive and/or the local legislature decide to move ahead with an emission inspection program. In addition, there may be serious legal shortcomings, as municipalities appear not to have adequate legal authority to mount inspection, maintenance and retrofit, depending upon the degree of "home rule" allowed under state law. Other legal problems (although of a different nature) will also arise where important proportions of the motor vehicle traffic in a given jurisdiction originate elsewhere (e.g., in Washington, D. C. where approximately half of motor vehicle traffic moving in the central city originates in Maryland and Virginia).

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[1] Northrop Corporation, Mandatory Emission Vehicle Inspection and Maintenance, Final Report (Anaheim, California: Northrop Corporation in association with Olson Laboratories, Inc., 1971), p. III-1.

Administering Agency

Assuming inspection programs are operated by some unit of state or local government, a determination must be made as to the appropriate administering agency. Currently, the administration of motor vehicle safety inspection programs varies considerably from state to state. At the present time, the majority of jurisdictions having safety inspection programs have mandated this responsibility to the commissioner of motor vehicles, but many other jurisdictions have assigned the task to state police, to the state health department, to the state highway department, to the state department of public safety, or to the state revenue department. Assignment of this responsibility will have an important bearing on the ease of administration of emission inspection programs. For example, motor vehicle agencies currently assigned the responsibility of safety inspection programs, may, if assigned the responsibility of emission checking, place higher priority on lane through-put than upon provision for sophisticated measurements required by some regimes for testing emissions.

CHAPTER 2

GASEOUS FUEL SYSTEMS

Definition of Terms

Within the near future (i.e., five years), only three types of gaseous fuels can be seriously considered as alternatives to gasoline for powering motor vehicles: liquified petroleum gas (LPG), compressed natural gas (CNG), and liquified natural gas (LNG). These fuels are inherently cleaner burning (produce fewer heavy hydrocarbons[1]) than gasoline owing to their lower molecular weight and carbon content. In addition, gaseous fuels ignite more rapidly and the combustion process proceeds more nearly to completion leaving less unburned fuel in the exhaust stream. Similar levels of emission reductions result from conversion to either LPG or natural gas.[2]

Modification to gaseous fuel requires the installation of a special carburetor (gas-air mixer),[3] special fuel tanks (pressure tanks for LPG and CNG, cryogenic tanks for LNG), pressure regulating devices, shut-off valves, and fuel lines. This is generally regarded as "simple" conversion as opposed to more sophisticated (and costly) modifications which may include: installation of a special venturi carburetor (to allow lean air/fuel mixtures at low power levels and enriched mixture at high power operations);

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[1] Heavy hydrocarbons contribute to the formation of photochemical smog.

[2] Due to differences in hydrocarbon reactivity, the combustion products emitted by natural gas powered vehicles are less conducive than LPG systems to formation of photochemical smog.

[3] Dual-fuel vehicles use the original carburetor in conjunction with an adaptor.

refined adjustment of engine variables; exhaust gas recirculation; exhaust air-injection thermal reactor system; and a catalytic converter. Vehicles modified to this extent, however, would probably have emission levels similar to those required by 1975 and 1976 for gasoline fueled operations (and therefore would be of little advantage from a pollution control point of view). Consequently, we confine the following to a discussion of simple conversion. For simple conversion, the cost of modifying an in-use light-duty vehicle to CNG or LPG ranges from $350 to $500, while conversion to LNG may cost from $800 to $1000.

Liquified Petroleum Gas (LPG)

Liquified petroleum gas (commonly referred to as propane) is a mixture consisting mostly of propane and butane, with vapor pressures ranging from 100 to 300 pounds per square inch at normal ground level atmospheric temperatures. Due to its economic advantages, LPG has been used as a motor vehicle fuel for many years and approximately 300,000 LPG powered vehicles are currently in operation.[1] LPG is transported in compressed liquid form by truck trailers and delivered to pressure storage tanks. It is then easily transferred as a liquid to vehicle storage tanks. Handling procedures are well known and relatively safe (odorants are available), and limited quantities of LPG are available in urban areas throughout the country. The travel range of typical LPG vehicles designed for street use is approximately 220 miles.

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[1] The breakdown by vehicle (or engine) type is: industrial fork-lift trucks 46.8 percent; farm tractors 25.0 percent; buses and trucks 15.6 percent; stationary engines 8.4 percent; automobiles 2.9 percent; and truck refrigeration units 1.3 percent. Institute of Gas Technology, Emission Reduction Using Gaseous Fuels for Vehicular Propulsion, Report submitted to the Air Pollution Control Office, Environmental Protection Agency (Chicago: Institute of Gas Technology, 1971), p. 4-38.

Natural Gas

Natural gas (consisting primarily of methane) may be used in compressed (CNG) form requiring heavy-wall, high pressure fuel tanks. High pressures (from 1000 - 2000 pounds per square inch) are necessary to store sufficient CNG for reasonable travel ranges. This in turn necessitates a compressor at refueling points in order to boost local gas distribution pressures. Although natural gas is relatively safe (odorants are available) from a flammability standpoint, the high pressures required may constitute a significant hazard in the case of breakage or disconnection of fuel lines or fittings. Approximately 2,000 experimental vehicles currently use compressed natural gas and a typical travel range is 70 miles.

Liquified natural gas (LNG) is currently being experimentally tested in approximately 200 vehicles. Unlike compressed natural gas, LNG must be transported from special storage facilities or liquefaction plants to refueling locations by LNG trucks. The liquid is then transferred to cryogenic vehicle storage tanks (no high pressures involved). There is currently no satisfactory odorant for LNG and therefore leakage could be hazardous. A typical travel range for LNG vehicles is 240 miles.

Air Pollution Control Potential

In this and the following section, we consider four issues which bear on the air pollution control potential of simple conversion: (1) how do emissions from LPG or natural gas powered motor vehicles compare with emissions from gasoline powered vehicles; (2) to what extent can any area's motor vehicle population be converted to gaseous fuel in the short term; (3) what would be the maximum realistically feasible reduction in emissions; and (4) what adverse side effects (from a pollution abatement point of view) can be anticipated.

Emissions from Gasoline and Gaseous Fueled Vehicles[1]

Accurate estimates of the emission reduction potential from simple conversion are not possible with present empirical data. These data (on exhaust emissions from gaseous fueled vehicles) are extremely limited and are based on a variety of different analytical test procedures and driving cycles. Moreover, the emission reductions achieved in each case are highly dependent on the specific engine type, conversion equipment, and engine adjustments. In order to achieve the maximum emission reduction it is necessary to "detune" the engine from manufacturers' specifications (e.g., ignition timing, fuel/air ratio).[2] For these reasons, reported test results vary considerably, and do not permit accurate predictions for in-use vehicle populations. Available data on individual vehicles, however, do show that significant emission reductions can be realized by converting pre-1975 cars to gaseous fuels. Tables 2-2 to 2-6 show the range of values which have been reported for conversion of various individual vehicles.[1] These reported results should be considered with reference to future federal new car emission standards (see Table 2-1), which would require even greater emission reductions than appear possible from simple conversion.

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[1] The present discussion concerns primarily the emissions from individual vehicles. A subsequent section, "Maximum Feasible Emission Reduction," discusses emission reductions for large fleets.

[2] According to the California Air Resources Board, the special carburetor to handle gaseous fuel must be carefully tailored to obtain low emission results. Low emissions will not result by making conventional conversion to these fuels, and this fact makes necessary the approval of these special carburetors and modifications by the ARB. California Air Resources Board, Reduction of Air Pollution by the Use of Natural Gas or Liquified Petroleum Gas Fuels for Motor Vehicles (Sacramento, Calif.: California Air Resources Board, 1970).

Table 2-1

FEDERAL EMISSION STANDARDS FOR
LIGHT-DUTY VEHICLES

Carbon Monoxide	3.40 grams/mile
Hydrocarbons	0.41 grams/mile
Nitrogen Oxides	0.41 grams/mile

Source: Federal Register, XXXVI, No. 228, Nov. 25, 1971, p. 22452.

Note: Standards for carbon monoxide and hydrocarbons are for 1975, for nitrogen oxides 1976.

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[1] It should be stressed that the data presented for gaseous fuel systems do not indicate the increase in emissions that would occur with accumulation of mileage. Deterioration of emissions control efficiency is currently being investigated by the EPA. Limited data obtained by the New Jersey Department of Environmental Protection indicate that accumulated mileage affects the emissions of gaseous fueled vehicles at least as seriously as those of gasoline fueled vehicles. (Verbal communication to Michael Keaton of Teknekron, Inc., October 14, 1971.)

Table 2-2

EXHAUST EMISSION DATA FROM EPA FOR GASEOUS FUELED VEHICLES

Vehicle	Fuel	Emissions in grams/mile HC	CO	NO$_x$
Converted 1968 Buick 350	LPG	3.5	4.7	8.9
Stock 1968 Buick 350		1.9	29.6	4.0
Converted 1969 Ford 351	LPG dual fuel	3.1	7.3	8.6
Stock 1969 Ford 351		7.4	37.8	5.2
Converted 1968 Ford 302	LPG dual fuel	2.4	4.2	1.8
Stock 1968 Ford 302		3.1	28.5	3.6
4 Converted 1969 Chrysler 318s	LPG dual fuel	2.4	7.2	2.9
Stock 1969 Chrysler 318		3.4	30.5	3.6
2 Converted 1969 Rambler 343s	LPG dual fuel	3.0	15.4	2.6
Stock 1969 Rambler 343		3.0	31.5	3.1
Converted 1969 Ford 429	LPG	1.3	4.0	1.9
10 Converted 1970 Ford 250s	LPG	0.69	1.8	2.6
10 Stock 1970 Ford 250s		3.70	16.0	9.4
10 Converted 1970 Rebel 232s	LPG	.51	3.9	3.1
10 Stock 1970 Rebel 232s		2.7	22.1	6.9
2 Converted 1968 Chevrolet 230s	CNG dual fuel	.54	9.5	---
2 Stock 1968 Chevrolet 230s		3.7	58.2	---
2 Converted 1969 Ford 250s	CNG dual fuel	.46	7.8	---
2 Stock 1969 Ford 250s		2.6	25.3	---

Source: Merrill W. Korth, Test and Evaluation Branch, Federal Motor Vehicle Pollution Laboratories, Environmental Protection Agency, Ann Arbor, Michigan. Personal communication to Michael Keaton of Teknekron, Inc., December 20, 1971.

Note: Blanks indicate no available data.

Table 2-3

EXHAUST EMISSION DATA FROM IGT FOR GASOLINE FUELED VEHICLES

Vehicle	Emissions in grams/mile		
	HC	CO	NO_x
1. Average of 63 1964 and 1965 vehicles using leaded gasoline.	23.90	73.20	5.30
2. Average of 59 1964 and 1965 vehicles using unleaded gasoline.	23.40	74.50	5.30
3. 1966 production small V-8 vehicles.	3.00	23.80	---
4. 1967 production vehicle with exhaust air injection system for HC-CO control.	2.60	23.00	5.00
5. Above vehicle modified with 15% exhaust recirculation.	2.04	25.40	1.10
6. 1967 production vehicle equipped with learner carburetion and retarded ignition.	1.84	24.20	8.55
7. Same vehicle as (6) with modified carburetion and ignition timing for reducing NO_x emission.	1.70	19.00	4.74
8. Same vehicle as (7) but with 15% exhaust recirculation added.	1.65	28.90	2.21
9. 1966 V-8 air injection vehicle with optimized jets and enriched carburetion, hotter spark plug, retarded timing, and exhaust recycle.	2.01	21.10	2.19
10. 1967 V-8 air-injection vehicle equipped with exhaust thermal reactor and enriched carburetion.	0.70	23.20	---
11. Above vehicle equipped with synchronized air injection and further enriched carburetion during acceleration.	---	6.20	0.48
12. Same vehicle as (11) with 11% exhaust recycle during partial throttle operation and temperature controlled enriched carburetion during acceleration.	---	6.50	0.50
13. Vehicle similar to (6) equipped with HC-CO catalytic converter. At start of catalyst durability test using unleaded gasoline. Hot cycle data.	0.33	2.90	---
14. Above vehicle after 50,000 miles.	0.72	3.40	---
15. Vehicle similar to (4) equipped with NC-CO catalytic converter. At start of catalyst durability test using unleaded gasoline. Hot cycle data.	0.08	2.80	---
16. Above vehicle after 50,000 miles.	0.41	3.10	---
17. Assuming a NO_x catalytic converter capable of 70% emission reduction is available and installed on vehicle (5) equipped with HC-CO catalytic converter.	0.07	2.90	0.80

Source: Institute of Gas Technology, Emission Reduction Using Gaseous Fuels for Vehicular Propulsion, Report submitted to the Air Pollution Control Office, Environmental Protection Agency (Chicago: Institute of Gas Technology, 1971), pp. 2-67 to 2-70.

Note: Some of the emission values are estimated weight-based figures converted from concentrations by assuming [illegible] lb. vehicle weight, and automatic transmission and using the 1970 procedure (Federal Register, XXXIII, No. 2, Jan. 1968). This calculation requires measurement of the emission concentrations in the exhaust and then assumes an average exhaust volume flow rate for each weight class of vehicle. While this procedure on the average requires equal mass emission control for different size vehicles, it does not recognize the variation in the exhaust volume flow rate for different vehicles in the same weight class. Blanks indicate no available data.

Table 2-4

EXHAUST EMISSION DATA FROM IGT FOR GASEOUS FUELED VEHICLES

Vehicle	Emissions in grams/mile		
	HC	CO	NO_x
1. A 1966 6-cylinder vehicle, converted to dual-fuel natural gas operation. California 7-Mode composite data, converted from concentrations.	1.00	2.9	---
2. Average of 5 vehicles (1967,1968, and 1969 models) fueled with natural gas, with or without retarded ignition and disconnected ignition advance. California 7-Mode hot-start cycle. Converted from concentration values.	1.48	3.0	1.01
3. Average of 7 vehicles (1968-1969 models having no emission control devices) converted to gasoline-propane dual-fuel operation. 1972 federal test procedure, cold start data.	2.54	9.0	2.62
4. Average of 7 vehicles (model unknown) converted to propane, tested according to 1972 federal 9-CVS procedure.	2.75	5.5	4.26
5. One of the 7 vehicles in (4), with 6-cylinder engine.	0.50	1.6	1.20
6. A 1970 V-8 vehicle converted to propane, equipped with variable venturi carburetor, lean air-fuel mixture, limited distributor advance, disconnected vacuum advance, and increased idle speed.	0.83	1.0	0.30
7. Above vehicle with a pair of catalytic HC-CO converters added.	0.45	0.8	0.43
8. Vehicle of (7) with enlarged catalytic chamber and slightly lowered compression ratio, hot-start data.	0.18	0.4	0.40
9. Above vehicle, cold-start data.	0.49	1.1	0.53

Source: Institute of Gas Technology, Emission Reduction Using Gaseous Fuels for Vehicular Propulsion, Report submitted to the Air Pollution Control Office, Environmental Protection Agency (Chicago: Institute of Gas Technology, 1971), pp. 2-73 to 2-74.

Note: Some of the emission values are estimated weight-based figures converted from concentrations by assuming 4000 lb. vehicle weight, and automatic transmission and using the 1970 procedure (Federal Register, XXXIII, No. 2, Jan. 1968). This calculation requires measurement of the emission concentrations in the exhaust and then assumes an average exhaust volume flow rate for each weight class of vehicle. While this procedure on the average requires equal mass emission control for different size vehicles, it does not recognize the variation in the exhaust volume flow rate for different vehicles in the same weight class. Blanks indicate no available data.

Table 2-5

EXHAUST EMISSION DATA FROM TRW
FOR UNCONTROLLED, CONTROLLED PRE-71, AND NO_x CONTROLLED VEHICLES

Control Type	Emissions in grams/mile					
	7-Mode Composite[1]			72 Procedure Mass[2]		
	HC	CO	NO_x	HC	CO	NO_x
Uncontrolled	6.9	66	4.4	(11.3)	(122)	(4.4)
-LPG	---	---	---	(1.4)	(8.4)	(1.1)
-Natural Gas	---	---	---	(1.0)	(17.6)	(2.1)
Controlled, Pre 71	3.9	31	6.3	(7.1)	(88)	(6.2)
-LPG	0.7	4.2	1.1	(1.4)	(8.4)	(1.1)
-Natural Gas	0.5	8.6	2.1	(1.0)	(17.6)	(2.1)
1971 NO_x Control	---	---	---	(4.3)	(51)	(6.3)

Source: TRW Systems Group, Emission Factors for Motor Vehicles (McLean, Va.: TRW Systems Group, TRW, Inc., 1971). Based on 24 LPG powered vehicles and 4 natural gas powered vehicles. Parenthetical values are calculated equivalent mass emissions from concentration data. Blanks indicate no available data.

1. Federal Register, XXXI, No. 61, March 1966.

2. Federal Register, XXXV, No. 136, July 1970.

Table 2-6

EXHAUST EMISSION DATA FROM CALIFORNIA ARB FOR GASEOUS FUELED VEHICLES

Vehicle	Fuel	Emissions in grams/mile		
		HC	CO	NO_x
Chevrolet 1969	LPG	0.56	2.9	0.45
Chevrolet 1970	LPG	0.48	2.9	0.56
Oldsmobile 1965	LPG	0.25	12.6	1.10
Chevrolet 1968	Natural gas	0.71	3.4	0.60
Jeep 1969	Natural gas	0.51	1.8	0.55
Ford 1969	Natural gas	0.82	4.5	0.48

Source: California Air Resources Board, Reduction of Air Pollution by the Use of Natural Gas or Liquified Petroleum Gas Fuels for Motor Vehicles (Sacramento, Calif.: California Air Resources Board, 1970).

Extent of Conversion

In our view, the conversion of large numbers of motor vehicles to gaseous fuels would be impractical or unwarranted in most major metropolitan areas for the following reasons:

1. Natural gas is presently in short supply and no major expansion in capacity is anticipated in the near future. Low supplies of LPG combined with preferential treatment for heating customers over fuel customers have already caused a reduction in conversions and loss of sales.

2. Conversion of large numbers of vehicles and implementation of an adquate fuel distribution system would be extremely expensive.

3. Adequate supplies of conversion equipment are currently not available. Consequently, at least two to

> three years would elapse before significant numbers of vehicles could be modified.[1]
>
> 4. Considerable efforts are currently under way to meet stringent 1975 federal emission standards through modification of conventional gasoline engines. If successful, these efforts would obviate the need for gaseous fueled vehicles, which would be unable to meet the above standards without engine modifications and substantial supplemental equipment (e.g., thermal and/or catalytic reactors).

In some metropolitan areas, however, fuel supplies, distribution systems, and conversion equipment may be adequate for small-scale conversions (e.g., commercial fleets). Such conversions may be warranted if (1) the vehicles to be converted account for a large proportion of vehicle miles traveled in a relatively small area (e.g., taxicabs in Midtown Manhattan); (2) the operations of these vehicles are of a low-speed, stop-and-go nature (which normally results in high emissions); (3) conversion could be effected rapidly so that large numbers of pre-1975 vehicles are affected; and (4) the converted vehicles would be regularly inspected and maintained.[2]

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[1] As indicated earlier, LPG is currently the gaseous fuel in greatest use for powering vehicles (approximately 300,000 LPG powered units are currently in operation). Only a small fraction of these however (less than 9,000) are light-duty motor vehicles, a number less than even a single fleet in one city (i.e., medallion cabs in New York City). Present production figures are also low. Nationwide, the total annual production of LPG carburetors is approximately 133,000 with only 12,000 sold on the East Coast. Approximately 140,000 suitable LPG tanks are produced in the United States and the number of LNG tanks produced is considerably less. Again, however, only a small fraction of these units would probably be available for powering light-duty vehicles. National LP-Gas Association, 1969 LP-Gas Market Facts (1970).

[2] It should be recognized that fleets generally have a much higher turnover rate than the general motor vehicle population. Consequently, the proportion of pre-1975 vehicles in such fleets will decrease rapidly as post-1975 vehicles become available. If investments in gaseous conversion equipment tended to discourage these normally high turnover rates, the conversion could be counterproductive from the viewpoint of air pollution control. (These observations of course assume that manufacturers of the new gasoline powered engines meet the 1975 federal standards.)

Maximum Feasible Emission Reduction[1]

Fleet and non-fleet medallion taxicabs produce an unusually large percentage of total motor vehicle emissions in New York City. In 1970, for example, 14.8 percent of the total carbon monoxide emissions from motor vehicles in Manhattan and 37.6 percent of the motor vehicle produced carbon monoxide in the Midtown Central Business District were attributable to medallion taxicabs. Projections for 1975 (assuming full compliance with federal new car emission standards) indicate 10.1 percent and 30.9 percent for Manhattan and the Midtown CBD, respectively.[2] Accordingly, conversion of Manhattan taxicabs to gaseous fuels offers a good indication of the maximum feasible emission reduction for this control.

Table 2-7 summarizes the initial reductions in aggregate emissions which are achievable from conversion of this motor vehicle population to gaseous fuels.[3] It is to be emphasized that these estimated emission reductions represent control beyond that which is expected to occur as a result of normal vehicle turnover rates and full compliance with federal new car emission standards. Table 2-7 shows estimated reductions as a percentage of total motor vehicle emissions; Table 2-8 shows estimates as a percentage of aggregate (i.e., light-duty only) motor vehicle emissions. Detailed calculations are presented in Appendix B.

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[1] This analysis is based on data from the New York City Environmental Protection Administration, Department of Air Resources, Proposed Plan for Meeting Federal Air Quality Standards Relating to Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, and Oxidants in New York City (New York: New York City Environmental Protection Administration, 1972).

[2] Motor vehicles account for 97 percent of carbon monoxide emissions in New York City in 1970 and a projected 98 percent in 1975.

[3] All estimates are for initial reductions and do not take into account deterioration due to accumulation of mileage. By "emissions" we refer to carbon monoxide; by "aggregate" emissions (or emission reductions) the carbon monoxide attributable to light-duty motor vehicles in any given area; by "total" the carbon monoxide emissions attributable to all motor vehicles.

Table 2-7

MAXIMUM FEASIBLE EMISSION REDUCTIONS FROM CONVERSION TO GASEOUS FUELS EXPRESSED AS A PERCENTAGE OF TOTAL MOTOR VEHICLE EMISSIONS

Extent of Conversion	Carbon Monoxide Emission Reductions[1]
Borough of Manhattan	
Conversion of all fleet and non-fleet medallion taxicabs in the 1975 Manhattan taxi population.	
Assuming 85.3% reduction from converted fleet vehicles and 90.6% reduction from converted non-fleet vehicles.	8.8%
Assuming 60% reduction from converted fleet and non-fleet vehicles.	6.0%
Conversion of all fleet medallion taxicabs in the 1975 Manhattan taxi population.	
Assuming 85.3% reduction from converted fleet vehicles.	5.4%
Assuming 60% reduction from converted fleet vehicles.	3.8%
Midtown Manhattan Central Business District	
Conversion of all fleet and non-fleet medallion taxicabs in the 1975 Midtown Manhattan Central Business District taxi population.	
Assuming 85.3% reduction from converted fleet vehicles and 90.6% reduction from converted non-fleet vehicles.	27.1%
Assuming 60% reduction from converted fleet and non-fleet vehicles.	18.5%
Conversion of all fleet medallion taxicabs in the 1975 Midtown Manhattan Central Business District taxi population.	
Assuming 85.3% reduction from converted fleet vehicles.	15.3%
Assuming 60% reduction from converted fleet vehicles.	10.8%

Source: Appendix B.

[1] Refers to reductions expressed as a percentage of emissions from all motor vehicles in Borough of Manhattan and Midtown Manhattan Central Business District respectively.

Table 2-8

MAXIMUM FEASIBLE EMISSION REDUCTIONS FROM CONVERSION TO GASEOUS FUELS EXPRESSED AS A PERCENTAGE OF AGGREGATE MOTOR VEHICLE EMISSIONS

Extent of Conversion	Carbon Monoxide Emission Reductions[1]
Borough of Manhattan	
Conversion of all fleet and non-fleet medallion taxicabs in the 1975 Manhattan taxi population.	
Assuming 85.3% reduction from converted fleet vehicles and 90.6% reduction from converted non-fleet vehicles.	13.0%
Assuming 60% reduction from converted fleet and non-fleet vehicles.	9.0%
Conversion of all fleet medallion taxicabs in the 1975 Manhattan taxi population.	
Assuming 85.3% reduction from converted fleet vehicles.	8.1%
Assuming 60% reduction from converted fleet vehicles.	5.7%
Midtown Manhattan Central Business District	
Conversion of all fleet and non-fleet medallion taxicabs in the 1975 Midtown Manhattan Central Business District taxi population.	
Assuming 85.3% reduction from converted fleet vehicles and 90.6% reduction from converted non-fleet vehicles.	58.7%
Assuming 60% reduction from converted fleet and non-fleet vehicles.	40.2%
Conversion of all fleet medallion taxicabs in the 1975 Midtown Manhattan Central Business District taxi population.	
Assuming 85.3% reduction from converted fleet vehicles.	33.2%
Assuming 60% reduction from converted fleet vehicles.	23.4%

Source: Appendix B.

[1] Refers to reductions expressed as a percentage of emissions from light-duty motor vehicles only in Borough of Manhattan and Midtown Manhattan Central Business District respectively.

The two values of "carbon monoxide emission reductions" estimated for each case (Tables 2-7 and 2-8) correspond to emissions data from two independent sources and serve to demonstrate overall sensitivity of estimates to varying assumptions about emission reductions from simple conversion for converted vehicle populations. The 85.3 percent reduction for fleet medallion taxicabs and 90.6 percent reduction for non-fleet medallion taxicabs correspond to a carbon monoxide emission factor of 5 grams/mile estimated by the Institute of Gas Technology.[1] The 60 percent reduction in carbon monoxide emissions for fleet and non-fleet medallion taxicabs is based on data from the New York City Implementation Plan.[2]

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[1] Estimated on the basis of simple conversion involving the installation of gaseous fuel system, pressure regulator, air-gas mixer, blocked manifold heat, and some minor adjustments of engine variables -- such as lean air/fuel ratio, slightly retarded timing, increased idle speed, and disconnected vacuum advance. Source: Institute of Gas Technology, Emission Reduction Using Gaseous Fuels for Vehicular Propulsion, Report submitted to the Air Pollution Control Office, Environmental Protection Agency (Chicago: Institute of Gas Technology, 1971), p. 3-11.

It should be noted that this estimate is basically an "initial" emission factor representing emissions from newly converted vehicles and does not account for the possibility of deterioration in control efficiency (i.e., increasing emission factor) with accumulated mileage. There appears to be no reliable data on control efficiency deterioration for gaseous fueled vehicles.

[2] New York City Environmental Protection Administration, Department of Air Resources, Proposed Plan for Meeting Federal Air Quality Standards Relating to Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, and Oxidants in New York City (New York: New York City Environmental Protection Administration, 1972), p. 4-27.

Since the New York City Implementation Plan considered conversion of fleet medallion taxicabs only, the 60 percent assumed reduction in per vehicle emissions is strictly applicable only to fleet vehicles. However, due to lack of specific New York City data on emission reductions for non-fleet taxicabs, the 60 percent reduction is assumed to be applicable to both fleet and non-fleet vehicles for the purposes of this calculation.

It is important to note that these estimated emission reductions do not necessarily imply a corresponding degree of improvement in ambient air quality. Localized improvements in air quality are in general rapidly degraded by diffusion of pollutants from surrounding areas, a consideration particularly pertinent to the Midtown Manhattan CBD. Nevertheless, significant improvements in street-level air quality in the vicinity of roadways may be expected.

Finally, it should be stressed that conversion of all fleet and non-fleet medallion taxicabs (almost 12,000 vehicles in operation) appears highly optimistic in view of the difficulties of inducing owners to modify to gaseous fuel systems (see below "Institutional Feasibility").

Institutional Feasibility

Earlier ("Extent of Conversion") we have alluded to the inadequacy of available fuel supplies,[1] the high cost of installing conversion equipment and implementing fuel distribution facilities for large numbers of vehicles and the presently limited production of conversion equipment. For these reasons, large-scale conversions would be impractical and unwarranted in view of the considerable efforts currently under way to meet future federal emission standards through modification of conventional gasoline engines.

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1. That natural gas is currently in short supply is commonly maintained by both industry and government sources. (See, for example, "Gas Shortage Poses a National Threat of Cutbacks," New York Times, November 21, 1971, p. 1, and "Board Make It Official -- We Don't Have Any Gas to Spare," Canadian Financial Post, November 27, 1971, p. 37). A recent staff report of the Federal Power Commission covering the next 18 years suggests that domestic production of natural gas is insufficient to meet expanding demand after 1975. See, U.S. Federal Power Commission, Bureau of Natural Gas. Natural Gas Supply and Demand, 1971-1990. Staff Report No. 2 (Washington, D.C.: Government Printing Office (FP 1.21:218), February 1972). This nationwide picture, however, varies somewhat when we look at specific areas.

In some heavily populated parts of the east, gas companies are refusing to take on large new users, and even some residences. Similarly, some government agencies have already moved to impose sweeping regulations on gas consumption. Last fall, for example, New York State's Public Service Commission required all utilities serving the state to reject all new industrial and commercial customers unless applicants could switch to alternate fuels in an emergency or unless they engaged in industrial processes that necessitated natural gas.

Conversely, some areas of the country are not so adversely affected. For instance, a study prepared for the California Institute of Technology concluded that supplies of CNG for the Los Angeles Basin are currently sufficient to replace up to 25 percent of all gasoline burned in the area. See, California Institute of Technology, Environmental Quality Laboratory, Smog: A Report to the People of the South Coast Air Basin (Pasadena, Calif.: California Institute of Technology, 1972), p. 15.

In some metropolitan areas, however, fuel supplies, distribution systems and conversion equipment may be adequate for small-scale conversions (e.g., commercial fleets) in highly polluted downtown (or other densely developed) districts. Aside from possible technical difficulties,[1] the principal institutional problems in implementing small-scale conversions may consist of (1) present safety regulations (at both state and local levels) which discourage or preclude gaseous fuels for motor vehicle use, (2) the considerable costs and risks for fleet owners and operators of converting to natural gas or LPG, and (3) the limited legal authority of municipalities over large vehicle fleet owners and operators.

State and Local Safety Regulations

Safety regulations in some jurisdictions presently prohibit the storage and/or transportation of gaseous fuels. In California, for example, any use of LNG requires approval of the State's Public Utility Commission, while transportation of the gas (including LNG-powered automobiles) is prohibited through some bridges and tunnels because of explosion hazards. Similar regulations exist elsewhere in the United States.

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[1] Even for small-scale conversion the principal technical problem is fuel distribution, since most metropolitan areas have very few fueling facilities (aside from some stations now selling small quantities of propane to campers). Installation, on the other hand, apparently presents no major problems according to ongoing road testing (e.g., the General Service Administration's dual-fuel experimental fleet), nor is performance adversely affected in any appreciable way.

These regulations, however, are often quite dated, in some instances prescribing safety specifications now known to be unnecessarily stringent. Until recently, for example, a New York City fire regulation drawn up in 1913 prohibited storage of gaseous fuels in containers appropriate for motor vehicle use.[1] Relaxing such regulations where they exist may not present a large difficulty; the New York City Council, has now passed a bill to permit storage of some gaseous fuels under certain conditions.

However, even if legal restrictions respecting storage are revised, transportation may be a problem. In New York City, for example, since LPG presents some safety problems (e.g., the transportation of large quantities through tunnels), Fire Department opposition has been sufficient to prevent the tanking of LPG even though no law specifically prohibits the activity. Similarly, New York City Fire Department safety standards (i.e., for stringent compressor safety requirements) for natural gas may significantly raise the cost and thereby discourage the use of natural gas as a fuel for fleets. As a result, the discretionary authority of some local agencies (e.g., fire departments and bridge and tunnel authorities) may preclude or discourage the use of gaseous fuels for motor vehicles even where regulations do not exist or have been revised.

Costs and Risks of Conversion

The costs of conversion to fleet owner/operators fall into two general categories: (1) initial capital investments in both vehicle conversion equipment (fuel tanks and lines, carburetor adaptors, etc.)

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1. Present knowledge about the properties of gaseous fuels does not dictate such stringent storage container regulations.

and pumping apparatus (compressor and storage tanks), and (2) disruptions to current operating practices (e.g., the need to develop new maintenance techniques, fueling patterns and supplier relationships). Benefits from conversion may include longer engine component life, less downtime, lower fuel costs (primarily due to state fuel tax savings) and (though not a direct cost saving to owner/operators) lower exhaust emissions. At present, however, little is known about the economics of conversion to gaseous fuels since only a few small scale conversion programs have been implemented. Lacking requisite data, we must confine the following discussion to several of the most salient cost considerations, as well as the risks to owner/operators inherent in conversion.

Conversion costs per vehicle range from $350 to $500 (for CNG or LPG) to $800 to $1,000 (for LNG).[1] Considerable costs are also involved for CNG fuel compressors (approximate cost in excess of $10,000), storage facilities for LPG and LNG (approximate cost of a 2,250 psi storage tank: $3,200 plus installation costs), and filters.[2] In addition, changes in operation (e.g., new maintenance procedures and schedules) may produce higher costs, although absent approximate data, these cannot be estimated at the present time.[1]

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[1] Institute of Gas Technology, *Emission Reduction Using Gaseous Fuels for Vehicular Propulsion*, Report submitted to the Air Pollution Control Office, Environmental Protection Agency (Chicago: Institute of Gas Technology, June 1971), p. 6-10. Per vehicle conversion costs may depend upon the number of vehicles undergoing conversion due to volume discounts, (costs per unit decreases as fleet size increases), and whether conversion equipment can be transferred to successive vehicles.

[2] *Ibid.*, pp. 5-8 to 5-9. Financing conversion to gaseous fuels tends to be easier for fleets whose vehicles are most intensively used (thus permitting rapid amortization of high installation costs). These, in turn, tend to be the larger fleets with newer vehicle populations (the bulk of vehicles in large fleets are less than two years old). From an air pollution control standpoint, however, fleets with older vehicles would gain more from conversion to gaseous fuels. Ironically, those fleets which stand to gain the greatest cost savings are also those which would contribute the least to reducing emissions on a per vehicle basis.

These conversion costs may be retrievable from reduced operating and fuel storage (for CNG) expenses. Experience to date with converted vehicles indicates that savings may include increases in the life of spark plugs and exhaust systems, as well as fewer oil changes.[2] What is more, fuel costs per mile appear somewhat less for gaseous fuels, the differential depending heavily on prevailing state fuel tax policy.[3]

While operating costs savings seem likely with conversion to gaseous fuels, considerable uncertainty exists as to whether all capital outlays involved in conversion can be recovered from reduced operating expenditures. (Again, the uncertainty arises primarily from the absence of any large scale conversion experiments on privately owned and operated fleets.) As a result, fleet conversion seems a risky venture to fleet owners.[1] In addition to large initial capital outlays, changes will have to be made in long'standing operating/maintenance practices[2] and supplier relationships. The reduced coverage of new car warranties may also be a source of concern to fleet owners; the warranty is void for any equipment failure which can be traced to the installation and functioning of the conversion system. And, there is always the possibility that lacking a well developed supply, distribution and marketing system, gaseous fuel may become temporarily unavailable.[3]

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[1] Operating costs may be sensitive to a number of variables including local fuel prices (including prevailing state fuel tax policies), fleet size and type of fueling operation.

[2] One source estimates maintenance savings from gaseous fuel conversion at 7 percent. See Institute of Gas Technology, Emission Reduction Using Gaseous Fuels for Vehicular Propulsion, Report submitted to the Air Pollution Control Office, Environmental Protection Agency (Chicago: Institute of Gas Technology, June 1971).

[3] Tax incentives and other legislated inducements by government bodies can significantly alter relative fuel prices. In California, the 6c per gallon tax for LPG or LNG (1c less than the corresponding gasoline tax) and the 7c per 100 cubic feet of CNG is waived if the fuel is purchased for use in a properly tuned and certified (by the state's Air Resources Board) motor vehicle.

Concomitantly, of course, loss in tax revenue could be considerable. The California Institute of Technology's Environmental Quality Laboratory has estimated that conversion of small fleets (trucks, taxis, buses and automobiles) to gaseous fuels (25 percent CNG and 8 percent LPG) could result in a 33 percent reduction in gasoline consumption. Based on the gasoline volume consumption of 4 billion gallons for 1969, this represents an annual decrease of 1.3 billion gallons or $143 million in annual state and federal tax revenue.

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[1] Compounding the perceived risk of gaseous fuel conversions is the fact that many fleet operators have lost confidence in the ability of one fuel, propane, to meet operating requirements. Some conversions have been poorly designed and even units designed specifically for propane have not always been satisfactory. For example, the Chicago Transit Authority operates the largest propane-fueled bus fleet in the world, but has not purchased any additional propane units since 1963. This is primarily due to the inavailability of equipment specifically designed to run on propane, but in addition the CTA does not wish to install engine conversion kits.

[2] In California, for example, maintenance schedules must be arranged to insure that vehicles are properly tuned for low emissions, a pre-requisite for the waiver of gaseous fuel taxes.

[3] Even if supply shortage problems can be overcome, distribution may also pose certain difficulties. In Los Angeles, for example, only some 50 service stations presently sell propane fuel (plus another 40 who sell propane to campers) and no such distribution system exists for natural gas (two pilot programs have recently been announced by the Union Oil Co. and the Pacific Lighting Corporation to be run in Riverside, California). See, California Institute of Technology, Environmental Quality Laboratory, Smog: A Report to the People of the South Coast Air Basin (Pasadena, Calif.: California Institute of Technology, 1972), p. 15. The usual practice is for CNG-converted fleets to have their own fueling facility, including a compressor and storage tank. However, since such equipment is costly and probably beyond the financial capabilities of small fleet operators, it would probably be necessary to provide some type of distribution infrastructure before requiring private fleet conversion.

Finally, and perhaps most important, there is the short time interval before 1975, at which time new car emission standards require emissions to be at least as low as current converted vehicles. Given the substantial initial costs and risks associated with conversion to gaseous fuels and the large proportion of new vehicles most fleet owners purchase each year, fleet owners would doubtless resist strongly any governmental attempts to require fleet conversion as a short-term air pollution control measure.

Legal Authority

In most cities, adequate legal authority to require fleet conversion does not appear to be a major problem, particularly in the case of taxis (usually already subject to government regulation).[1]

Since most jurisdictions currently inspect their taxicabs periodically for safety criteria (usually through the local Bureau of Motor Vehicles) and since most city councils have the legal authority to regulate taxis (through ordinances), adequate authority exists to require and enforce taxi fleet conversion to gaseous fuels. The main problems are less likely to be legal than political: the resistance by powerful taxi fleet owners.

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[1] The governmental agency which regulates taxi operations varies from jurisdiction to jurisdiction. Often the city council is the predominant authority, either directly or indirectly. In New York, the City Council is the chief promulgator of regulations for the taxicab industry, but its regulations are enforced by the Taxi and Limousine Commission. In the Chicago and Washington metropolitan areas, several governmental agencies have authority over the industry, and depending upon the area involved, are often subject to local city council approval. In the majority of cases, the taxi industry is regulated by municipal agencies through local ordinances (although some states regulate their taxis through the state public utilities commission).

Taxi owners in large metropolitan areas are commonly organized in some form of association and as a result, their ability to forestall regulation (e.g., mandatory conversion) may be significant. The natures of local taxi industries (as well as of regulatory bodies) varies considerably, of course, and thus it is not possible to predict at this time the way political opposition might arise. However, if experience from other areas of government regulation is any indication, industry resistance may express itself in many ways. Industry representatives may persuade the regulatory body on the basis of studies or "expert witnesses" that regulation would be so burdensome or costly as to preclude even consideration in the form of hearings or research. Or the industry may prolong hearings by repeatedly raising new issues or generating public concern. Or industry representatives may simply await the completion of all public proceedings and then file for a court injunction to suspend further action.

CHAPTER 3

TRAFFIC FLOW TECHNIQUES

Definition of Terms

As used in this report, "traffic flow techniques" refer to those traffic engineering measures that have as their principal objective a reduction in delays, idling periods and stops and starts which, in turn, would tend to increase average vehicle speeds[1] on the existing street system.[2]

In considering traffic flow techniques, it is desirable to keep in mind the hierarchy of facilities -- ranging from freeways to arterials to local city streets[3] -- that service large metropolitan areas. Depending on which type of facility is improved, traffic flow techniques offer differing potentials for air pollution control. For example, because of their grade-separated characteristics urban freeways afford the potential for higher average vehicle speeds than any other parts of the street system.[1] Also implicit in their design is the objective that no stopping is required (assuming loading at design volumes and normal operating conditions). Because access is controlled, some traffic flow techniques (e.g., ramp metering) can be used to control the volume and lane density of vehicles on the facility.

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[1] A secondary result of some traffic flow techniques (e.g., ramp metering, prohibition of on-street parking) may be to reduce vehicle volumes along given roadways. Measures to this end are considered in Chapter 6 on "Motor Vehicle Restraints." For purposes of the present chapter, however, we focus primarily on the objective of increasing the speed at which traffic flows. The term traffic flow as it is generally used in traffic engineering includes not only the "quantity" aspects of the word flow (i.e., vehicle volumes at given speeds), but also the "quality" aspects (i.e., the uninterrupted character of the flow). From an air pollution control point of view, the quality can be as important as the quantity, since motor vehicle emissions are a function of both average vehicle speeds and stops and starts. It is in this latter sense (i.e., both quality and quantity) that "traffic flow" is used in this report.

[2] Because of the short time frame for this study, emphasis here is upon improving existing facilities, not new construction. Construction of new urban highway facilities is a time-consuming practice which would involve the entire metropolitan planning, funding and implementation process. Consequently, major changes would not be possible within five years.

[3] As commonly used, "freeways" refer to highways with full control of access, with all intersections fully grade-separated. Typically, freeways accommodate large traffic volumes at high speeds. "Arterials" refer to those streets either divided or undivided that have the main function of carrying "through" traffic at medium speeds. "Local streets" refer to streets that have the main function of providing access to adjacent properties, and are not intended to carry "through" traffic.

Arterials and local streets, on the other hand, are characterized by frequent grade intersections, sometimes unrestricted midblock access and traffic signals. Traffic on arterials and local streets is also relatively more susceptible to interruptions by pedestrians, truck deliveries, parking and transit buses than is freeway traffic. All of these factors result in friction that causes relatively lower vehicle speeds and more stops-and-starts. Furthermore, the potential for pollution control from smoothing traffic flow in downtown areas is limited in many instances (e.g., widening intersection approaches) by the already densely developed nature of the central business district (CBD). Usually, it is on or near these downtown facilities where the highest traffic and population densities are found, and where emission reductions would be most required. More will be said on these matters in the "Air Pollution Control Potential" section of this chapter.

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[1] However, as discussed below, because of the speed/emission relationship the higher ranges of freeway speeds (as well as their relatively free flow) may be less relevant to air pollution control than the low average vehicle speeds and stop-and-go traffic characteristic of arterials and local streets.

Traffic flow techniques appropriate for the existing streets fall into four categories: (1) modification of street use, (2) increases in effective facility size, (3) pedestrian controls, and (4) traffic controls. These categories are listed in an approximate order of the complexity of making changes. For example, street-use modifications include lane markings which involve paint and manpower, whereas traffic controls range from traffic signals to computerized control and surveillance systems which require complex equipment, construction and planning. In this section we discuss the most relevant traffic control techniques in each category, summarize the salient experience, and identify the major results from a transportation point of view. In subsequent sections, we assess the air pollution control effect of these techniques and their institutional feasibility. Differing policies for different vehicle types[1] are considered in more detail in the chapters on motor vehicle restraints and improvements in public transportation.

Modification of Street Use

A variety of techniques may be employed to modify use of the street system. For example, streets may be modified to carry traffic in several alternative arrangements, depending on demand by time of day. These alternative arrangements may involve changing the direction of flow, or the number of lanes in each direction, controlling turning movements, modifying traffic patterns at intersections, and so forth. Details are summarized in Table 3-1.

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1. For example, bus priority systems (e.g., programming traffic signals to prolong green time for loaded buses) could be used to improve the flow of buses on city streets.

Table 3-1
(page 1 of 3)

MODIFICATIONS IN STREET USE

Technique	Description	Experience
One-way streets	Traffic flows in one direction only. Adjacent streets are paired so as to serve both directions of travel. Primary purpose is to eliminate conflicts between left turn and through vehicles at intersections, eliminate conflicting requirements of opposing traffic, and make possible more efficient signal progression. However, one-way street systems also entail longer trips for some vehicles, make some transit service less desirable, and can often confuse motorists by requiring irregular routing.	Widespread use in many American cities. One-way operation is most desirable where large turning movements conflict with two-way operations, where signals are closely spaced (making two-way signal progressions impossible) and where directional distribution of flow is fairly balanced during all time periods of the day. Hence, one-way street systems are particularly suitable to downtown areas characterized by large volumes of circulating traffic and closely spaced intersections. Primary purpose is to meet short term, highly directional traffic demands experienced in many metropolitan areas during periods of peak traffic flow and to provide for more efficient use of facilities.
Reversible lanes and streets	One or more lanes are designated for movement in one direction during one part of the day and the opposite direction for another part of the day. Technique is applicable to bridges, tunnels and wide arterials. It is possible on freeways if so designed and constructed.	Presently used for many arterial operations including Boston, Chicago, Cleveland, Detroit, Los Angeles, and Washington, D. C. Also used in many American cities to improve arterial operations to utilize existing facilities for more capacity.

Table 3-1
(page 2 of 3)

Technique	Description	Experience
Turning movement controls	Variety of methods may be employed, ranging from prohibition of turning at peak hours to provision of special right and left turning lanes at all times. Primary purpose is to prevent delays behind turning vehicles and hence to smooth traffic flow.	Widespread use on arterials in most American cities.
Median Controls	Structural or painted lengthwise division of a two-way street, arterial or freeway. (Note: additional space can sometimes be achieved by prohibiting parking on one or both sides of the street.) Primary purpose is to reduce mid-block friction by preventing mid-block left turns and U turns.	Widespread use on arterials; some on local streets in American cities.
Signs and pavement markings	Provide drivers with advisory information to permit better selection of existing facilities. Techniques include: (1) street signs, (2) longitudinal pavement markings; (3) transverse pavement markings (i.e., to indicate stopping locations) and pedestrian safety areas, (4) guide signs (i.e., to indicate upcoming turns, exits and so forth), and	Widespread use on freeways, arterials and local streets in American cities.

Table 3-1
(page 3 of 3)

Technique	Description	Experience
Signs and pavement markings (cont'd)	(5) driver advisory information displays (i.e., to advise of freeway traffic conditions and encourage use of alternative routes in times of congestion.)	
Channelization	Direction of traffic into appropriate lanes so as to assure smooth flow of merging and diverging streams. Simplifies turning movement conflicts and permits more effective signal control.	Currently in use in many American cities where street systems are characterized by non-grid configurations, many opportunities are available for reducing traffic conflicts at intersections.

Increases in Effective Facility Size

In many instances, the full width of urban streets is not effectively utilized for traffic movement with the result that congestion and accompanying air pollution are exacerbated. For example, it has been established that the usable width of an intersection approach has the greatest bearing on the capacity of that approach. Thus, for purposes of smoothing traffic flow, wide lanes are preferable to narrow ones, and in most instances three wide lanes will carry as much traffic as four narrow ones. Many cities, however, still use narrow lanes.

For increasing effective facility size within the time frame of this study (i.e., within five years), there are two major possibilities: (1) restricting on-street parking, and (2) widening intersection approaches. (Widening intersection approaches, it should be noted, is often impossible on downtown local streets where development is already dense; however, on many arterial streets widening intersection approaches is frequently possible with minor construction.) Details are summarized in Table 3-2.

Pedestrian Controls

Current practice regarding pedestrian controls varies widely, as do the characteristics of pedestrian traffic itself. Although traffic engineers agree in principle that pedestrians and vehicles should not mix, practical and economic considerations prevent such total separation. However, pedestrians must be accommodated and protected. In view of the volume of pedestrian traffic in most urban areas (and especially in the six cities considered for this study), very few alternatives have been

Table 3-2

INCREASES IN EFFECTIVE FACILITY SIZE

Technique	Description	Experience
Curb-lane controls	Controls would prohibit curbside parking and/or standing, and could apply generally, in critical areas, or during specified periods.	In many cities, curbside parking is presently restricted on arterials during peak traffic periods. Extent of enforcement of this prohibition, however, varies considerably from city to city.
Widening of street within existing right of way; widening approaches to intersections	Section of street cut out between intersections or at approaches. The former provides facilities for loading and unloading passengers and goods, thus reducing mid-block frictions and removing impediments to traffic flow. The latter facilitates traffic flow through intersections.	Currently in use for bus stops, taxi stands, and sometimes for truck loading. Widespread use in many American cities.

considered to existing arrangements (i.e., principally crosswalks at intersections). Indeed, many sweeping renewal projects in downtown areas seem to ignore the problem, and few have made any provision for adequate separation of facilities. Pedestrian overpasses have become an essential part of many expressways and mass transit improvements, but most downtown arterial applications have been makeshift in character. Pedestrian prohibitions and controls are generally difficult to enforce.

In some downtown areas, pedestrian malls and similar installations have contributed to removing pedestrians from arterial intersections. No comprehensive program of pedestrian controls has been implemented as yet in any American city. Consequently, crosswalks at intersections are still the standard provision for the interfacing (and hence the interfering) of pedestrians and vehicles.[1] Details are summarized in Table 3-3.

Signalization[2]

Traffic signals are probably the single most important measure to improve traffic flow. Their commands are unquestionably obeyed. One

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[1] At signalized intersections, the accommodation to pedestrians in their relatively slow pace of approximately four feet per second is an a priori constraint on signal timing. Depending upon demand, pedestrians are accommodated in various ways. For example, light pedestrian traffic may be handled safely with simple crosswalks, if clear stop-and-go signs or other indications are visible to pedestrians. Heavy pedestrian traffic, in turn, may be accommodated through provision of actuated concurrent pedestrian phases and pedestrian indications. A number of other possibilities are available, of course, depending upon vehicle controls, volumes and pedestrian demand.

[2] Broadly defined, signalization encompasses phasing and sequencing of intersections, timing of intervals, allocation of green time, progression enforcements and offsets.

Table 3-3

PEDESTRIAN CONTROLS [1]

Techniques	Description	Experience
Crosswalks	Range from the "standard" crosswalk, whereby pedestrians cross streets on green light and/or "walk" signal, to more sophisticated systems (e.g., exclusive pedestrian phase coordinated to provide selectable vehicular progression between the adjacent signalized intersections).	In widespread use in American cities of all sizes.
Overpass/Underpass	Permanent pedestrian walkways constructed over roadway.	Often used over urban freeways and arterials.
Barriers	Permanent fence or posts with connecting chains located near the edge of sidewalk.	Limited use in some downtown areas of American cities.
Bi-level Development	Promenades, pedestrian walkways, galleries, etc.	Atlanta, Philadelphia, Minneapolis.

1. Experience with pedestrian malls and various vehicle-free zones is summarized in Chapter 6, "Motor Vehicle Restraints."

recent study of eleven experiments with signal controls (five involving single intersections and six involving coordination of signals on arterials or in networks) concluded that:

> The signal system of a downtown area is the most important element of all the control media available. Very minor changes of signal timing produced large improvements to traffic flow. Many other types of improvements should be considered subservient to the needs of the signal system. Among these are restrictions to parking at intersection approaches, locations of bus stops, provision of separate left-turn lanes, mandatory lane use, and channelization -- all of which, at least to some degree, are involved in optimizing the signal system. The ability to organize successfully progressions depends largely on the reduction of frictions by use of these other control media.[1]

In conventional practice, most signal systems are not computer controlled; their operational programs are predetermined and based upon estimates of flow, historical data, averages and observations. Given the requirement that cross-traffic on city streets be accommodated, the potential for improvements with a modern signal system is substantial. As one recent survey of the state of the art noted:

> Everyone has experienced frustrating stops at traffic signals that appear to be needless because nobody on the other street is using the intersection either, and everyone has been caught in huge queues on the approaches to signals.

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[1] Highway Research Board, National Cooperative Highway Research Program Report 113, Optimizing Flow on Existing Street Networks (Washington, D.C.: National Academy of Sciences-National Academy of Engineering, 1971), p. 3.

> Because of the ubiquity of these situations, and because, even in the most freeway-oriented cities, upward of 60 percent of all travel is on streets that have traffic signals, any improvement in timing the red and green intervals would have an enormous payoff . . .[1]

However, the same survey notes:

> . . . there is nothing on the horizon that will justify statements to the effect that electronic surveillance and high-speed computers can eliminate congestion in urban areas, or 'double the capacity' of the surface street system.[2]

In fact, the authors warn :

> It should be noted that the maximum increase in throughput attainable by any control method (ramp metering or otherwise) cannot exceed the amount by which present throughput [throughput is defined as the rate of accommodating vehicle-miles of travel] is less than capacity. There are very few miles of freeway in the U.S. where this difference is more than 10 to 25 percent, and even there, only during peak hours.[3]

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[1] Highway Research Board, National Cooperative Highway Research Program Report 84, Analysis and Projection of Research on Traffic Surveillance, Communication and Control (Washington, D. C.: National Academy of Sciences-National Academy of Engineering, 1970), p. 2.

[2] Ibid. In view of what might be considered a lagging state of the art in the application of modern signal systems, the computer affords additional advantages. The traffic engineer with a well-designed, computer-controlled system will be able to pursue his art more effectively, and will be able to experiment and to evaluate his experiments. Furthermore, the equipment can be set up to maintain surveillance over itself so that hardware maintenance and adjustments are simplified. Finally, the computer can facilitate implementation of the improvements that will inevitably result from advances in the technology of traffic control.

[3] Ibid.

The potential for improving traffic flows through the use of computerized traffic signals is probably substantial. In one large city where computer-controlled traffic signal timing tests were conducted, reductions in travel time ranged from 26 to 39 percent and reductions in the number of stops ranged from 60 to 86 percent. In another city, network delays were reduced by 14 percent and the probability of a vehicle being stopped was reduced by 17 percent. In a medium-sized city, delays were reduced 18 percent and peak hour average speeds were increased between 10 and 15 mph.[1]

From city to city, however, the room for improvement varies widely, depending largely upon the base-line operating characteristics of the street network before computerization. If the original signal system is already based on skillfully engineered traffic control programs, it is entirely possible that little or no traffic flow improvements would be possible. In addition, the gains from computerization are apt to be large at the outset of the program when the "programming" capacity of the computer makes initial (and in a relative sense easy) improvements possible. However, after these initial gains, the range of possibilities will narrow and improvements will rest on the imagination and skill of the traffic engineer -- not on some inherent quality of the computer.

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1. Information derived from Highway Research Board, National Cooperative Highway Research Program Report 84, Analysis and Projection of Research on Traffic Surveillance, Communication and Control (Washington, D. C.: National Academy of Sciences-National Academy of Engineering, 1970).

Air Pollution Control Potential

Simply stated, motor vehicle exhaust emissions (carbon monoxide and hydrocarbons) are lower in freely-flowing traffic than in congested, stop-and-go conditions. There is some evidence that the converse holds for nitrogen oxides (i.e., that NO_x emissions increase with increased vehicle speeds).[1] Assuming an established relationship between emissions and speed, what increases in average vehicle speeds and accompanying carbon monoxide reductions can be anticipated from traffic control and flow improvements? Straightforward as this question may seem, a simple answer is not easily given because of a number of complicating factors discussed below.

Site-specific Nature of Improvements

From a pollution viewpoint, the degree of potential improvement depends in large measure upon the baseline speeds prior to implementation of traffic flow techniques. For example, increasing average vehicle speeds from 5 to 10 miles per hour is much more important from an air pollution control point of view than increasing average vehicle speeds from 25 to 30 mph. In turn, baseline speeds depend upon such factors as the physical characteristics of the urban street network under consideration, the existing traffic volumes and available capacity, anticipated growth and so forth. All of these factors are city (site) specific and must be so treated.

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[1] This general statement, however, ignores a number of important complicating considerations which are treated in Appendix C of this report.

Facility Evaluation vs. Network (System) Evaluation

Any accurate evaluation of the impact of traffic flow improvements must take into account network (system) repercussions, i.e., those repercussions which extend beyond the specific facility being improved. Unfortunately, however, most available data as to the impact of potential improvements are for specific facilities and not for entire networks. It may be highly misleading to consider an improvement strictly in terms of the specific facility. For example, installation of one-way streets can greatly improve the speed of traffic along the specific roadway in question, but there are offsetting disadvantages in that longer trips may be required by many motorists and vehicle miles traveled could increase.[1] Similarly, traffic using one-way streets might well be but a tiny fraction of vehicle volumes for the system as a whole. Hence, any prospective one-way system for air pollution control purposes should be studied in terms of its impact upon the entire street network.

System-wide evaluations should also consider larger areas than would be required for specific facility improvements. In addition, longer time periods (perhaps several years in some cases) would be needed so as to allow for all secondary and tertiary repercussions and adjustments to work themselves out. For example, it is well established that increased travel speeds (and therefore shorter triptimes) eventually generate longer trips. Therefore, a consequence of improved traffic flows (absent motor vehicle restraints) could well be higher vehicle miles traveled with accompanying greater (though perhaps more dispersed) emissions.

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[1] To evaluate the air pollution control potential of a one-way street system, a traffic assignment model (i.e., one which models the motorist's route selection between two points or a set of points) must be prepared to determine whether increases in speed or increases in vehicle miles traveled would be the dominating factor.

Annual Traffic Growth

Annual growth in the volume of urban traffic is usually considered to consist of two components: (1) a long-term trend associated with rising incomes, population and motor vehicle ownership, and (2) "induced" or "generated" travel which results from the provision of some improvement (e.g., comfort, convenience, reduced trip time) or added capacity in the street or highway network.[1] Both components of annual traffic growth can be illustrated with data drawn from cordon counts taken for Chicago and Washington, D.C.

The long-term trend of traffic growth into and out of the Chicago CBD is shown in Figure 3-1. From a total (entering and leaving) of about 324,865 vehicles in 1946, traffic in 1971 reached 470,563 -- an annual average growth rate of 1.5 percent. Another example of long-term growth and induced traffic is illustrated in Figure 3-2 with traffic data for Washington, D.C. The figure shows annual passenger vehicle traffic volumes on the major Potomac River crossings from 1965-70. From 1965 through 1970, inbound passenger vehicle traffic at all Potomac River bridges increased from 136,892 to 174,171 -- an average annual increase of about 5.0 percent.

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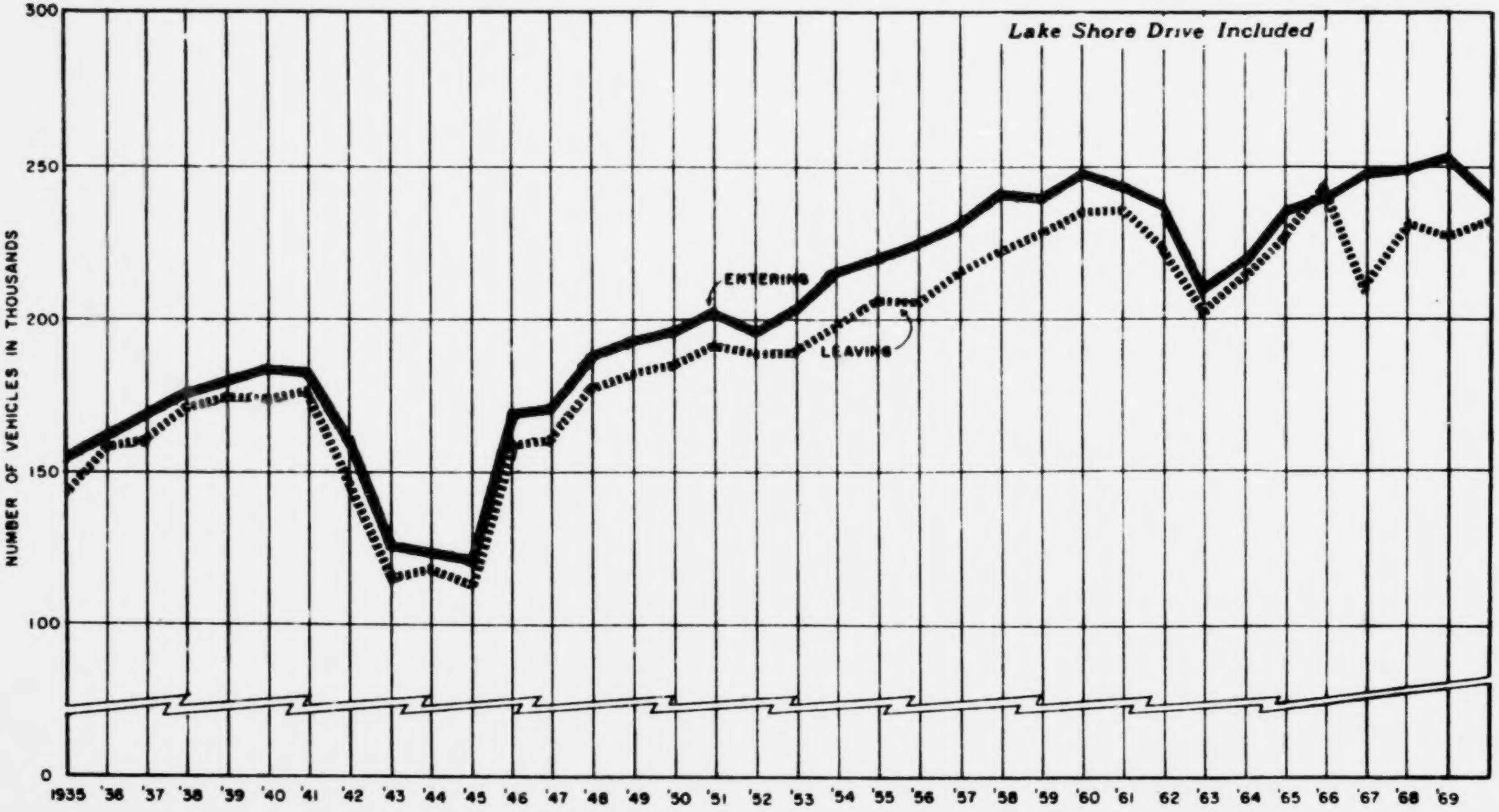
1. Other kinds of analysis which may be considered are hourly (particularly for peak periods), daily (e.g., work days and weekends) and seasonal variations. It is conceivable that traffic flow improvements by attracting more traffic (i.e., induced travel) could increase peak hour traffic volumes on the existing street systems. The increased volumes could eventually result in a return to former average speeds but with higher traffic volumes and therefore higher levels of emission than existed before the traffic flow improvements were in place.

Figure 3-1

DAILY NUMBER OF VEHICLES ENTERING AND LEAVING THE CENTRAL BUSINESS DISTRICT OF CHICAGO
BOUNDED BY ROOSEVELT ROAD, LAKE MICHIGAN AND THE RIVER
7:00 A.M. TO 7:00 P.M. TYPICAL WEEKDAY IN MAY 1935 to 1970

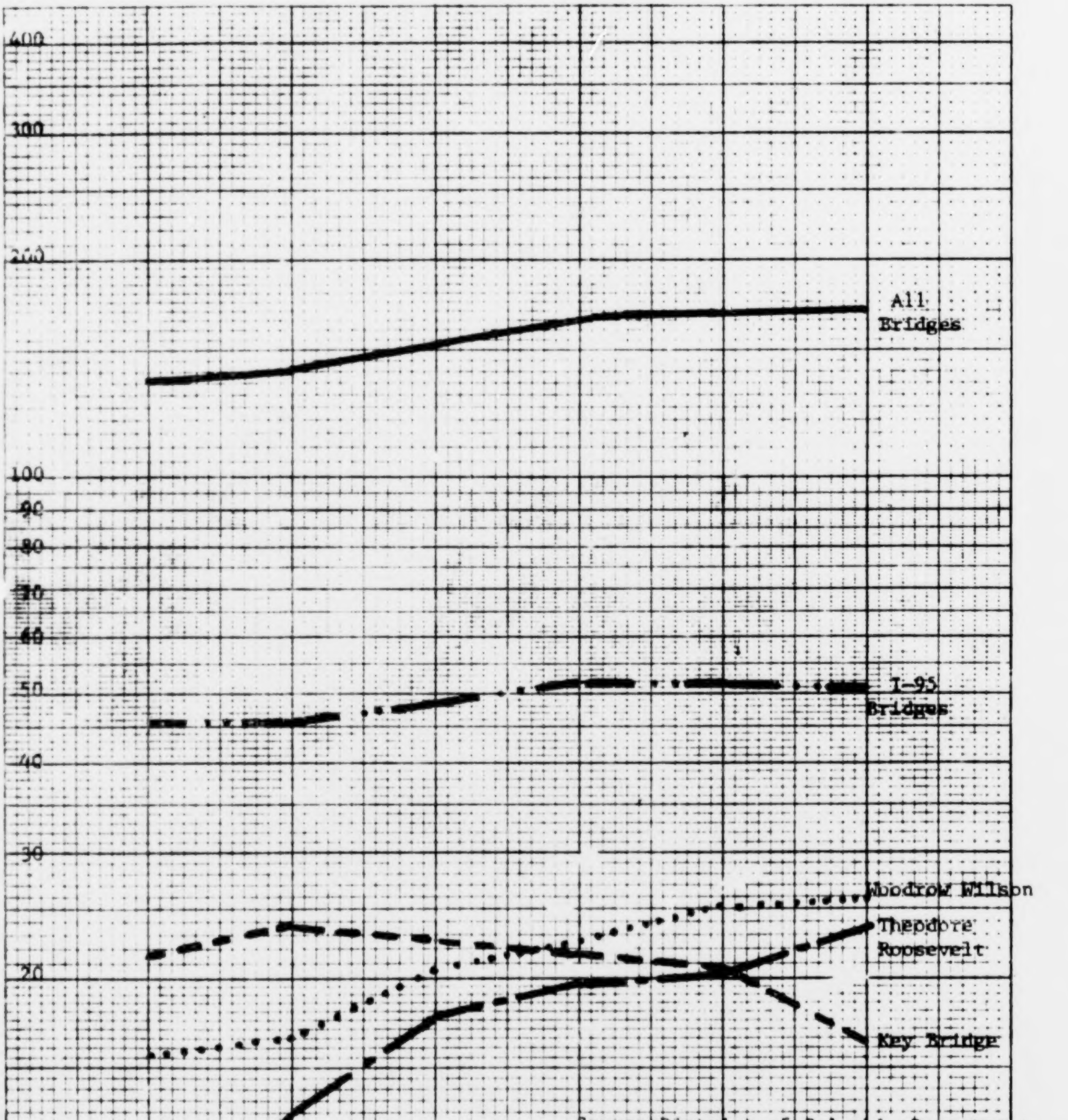


Source: Chicago Bureau of Street Traffic, 1970 Cordon Count: Central Business District

Figure 3-2

WASHINGTON D.C. CORDON COUNTS-POTOMAC RIVER BRIDGES
12-HOUR INBOUND VOLUMES
(6:00 A.M. - 6:00 P.M.)

1965-1970



Source: District of Columbia Department of Highways & Traffic, D.C. Cordon Traffic Survey 1970, Table A6-1.

In the long term, as new capacity is added to the street and road network, traffic growth results from the long-run forces of rising incomes, population growth and increased levels of motor ownership shown in Figures 3-1 and 3-2. However, because in the short run (say within a period of three to five years) the available street capacity is relatively fixed in most large urban areas, peak-hour capacity is usually saturated with traffic (i.e., congestion). Cordon count data for Chicago (Figure 3-1) suggest that as streets providing access to the Chicago CBD become saturated, congestion acts as a restraint to the use of the automobile (thus, the slower rate of increase from 1963 to 1970). In Figure 3-2 for Washington, D.C., the volume of traffic remains relatively stable (increases, but very slowly) except when there are changes in the form of either added capacity or improvements in existing capacity. These changes could result in higher speeds and/or shorter travel times; the latter, in turn, could generate new trips until once more congestion acts as a constraint on the use of the automobile.

Analysis of the data in Figure 3-2 shows that with the opening of the Theodore Roosevelt Bridge in June 1964, traffic was probably diverted from Key Bridge (already characterized by congested conditions). However, the combined Potomac River crossing traffic continued to grow with the availability of additional bridge capacity.

An illustration of the induced travel which can result from new capacity may be found in a study of the impact of Chicago's Congresss

Street Expressway on arterial and local streets in the area.[1] The study (a "Before" and "After" [1959 and 1961] examination of the traffic within a 16-square mile area around the expressway) noted that there was a 21 percent increase in total vehicle-miles of travel within the study area over the two-year period -- an annual rate of increase which was three times the normal Chicago increase of 3.5 percent a year or 7 percent for the two-year period under study. Thus there was a growth of about 14 percent over what was considered normal for Chicago based on traffic counts made in 1953, 1956 and 1959. Although a part of this 14 percent difference was probably traffic attracted from outside the study area, some of the increase was doubtless due to "induced" travel which would not have occurred in the absence of highway improvements.[2]

In most urban areas, there exists a condition of "capacity saturation" especially during the peak hours when the demand for access to work is highest. This capacity saturation results in latent or "pent-up" demand which can manifest itself in added trips whenever new capacity is provided or improvements result in improved travel times similar to added capacity). This latent demand accounts to a considerable extent (though not entirely by any means) for what is known as induced or generated trips.

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[1] See Frederick F. Frye, "The Effect of an Expressway on the Distribution of Traffic and Accidents," (paper presented at the 42nd Annual Meeting of the Highway Research Board, Washington, D.C., January 1963), cited in J.R. Meyer, J.F. Kain, and M. Wohl, The Urban Transportation Problem (Cambridge, Mass.: Harvard University Press, 1965), pp. 77-78. The net amount of the 14 percent which might be attributable to "induced" traffic is not clearly stated.

[2] Meyer, Kain and Wohl (Ibid.) suggest that "most of the difference is probably a result of traffic attracted from arterial and local streets outside the 16-square mile study area" (p. 77) but do not present data to support this conclusion.

The rapidity with which traffic builds up in response to new or improved facilities will depend on many factors including the existing traffic density on the present street network (i.e., the extent to which the streets are saturated). However, even where capacity saturation is found, overall traffic volumes in most U.S. metropolitan areas (and certainly for the cities of Chicago, Washington, D.C., San Francisco and Los Angeles) will continue to grow -- probably at a rate of about 2 to 4 percent a year.[1] For example, data for Manhattan bridge and tunnel crossings for New York City for the period 1963 through 1970 show that passenger vehicle crossings increased at an annual average rate of 2.7 percent.[2] In Los Angeles, data for the downtown area developed from cordon counts indicate that: "There has been a trend of steadily increasing cordon area vehicular travel since 1967, subsequent to the completion of the Santa Monica Freeway route, last leg of the downtown loop, in the early part of 1965."[3] A comparison of the number of passenger cars inbound to the Los Angeles downtown between 1967 and 1970 indicates an annual growth rate of 3.7 percent per year.[1]

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[1] In some of the large cities, growth into and out of the CBD may be stabilized, but improvements in capacity resulting in lower travel times or added capacity may be expected to generate added traffic. For example, the additions to tunnel and bridge facilities in New York City appear to be at capacity levels of operation within two years of their completion.

[2] New York Environmental Protection Administration, "Proposed Plan for Meeting Federal Air Quality Standards Relating to Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, and Oxidants in New York City," New York, 1972. (Mimeographed draft.)

[3] City of Los Angeles, Department of Traffic, Cordon Count: Downtown Los Angeles May 1970, p. 24. (Mimeographed.)

From a pollution viewpoint, both long-term traffic trends and induced travel tend to limit the air pollution control potential of traffic flow improvements in the medium- and long-term period. In most metropolitan areas, the additional capacity afforded by traffic flow improvements would tend to be "used up" within two to four years because of the higher volumes which would be attracted. Travel induced by substantial traffic flow improvements (i.e., far greater than the present levels of highway and street improvement programs) could contribute an additional amount of growth in the downtown street network as latent-demand is activated. These higher growth rates, of course, could consume additional capacity even more rapidly.

Impact of Traffic Improvements on Speed

Appraisal of the network impact of traffic flow improvements on speed requires a data base presently not available. To begin with, there is no comparability for existing data, all of which relate to specific traffic flow techniques implemented in specific cities at specific sites. The site specific nature of traffic flow improvements has already been discussed. Second, even if (judgmentally) comparable experience were examined, the data typically available does not include observations over a period long enough to enable evaluation of major repercussions; only the most immediate impacts are usually measured. Furthermore, traffic flow improvements at one point of the street network (e.g., at a specific set of intersections) frequently result in deterioration in traffic conditions at some point; typically, however, these network-wide trade-offs are never considered. Data from one recent study which did consider these trade-offs are summarized in Table 3-4.

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[1] City of Los Angeles, Department of Traffic, Cordon Count: Downtown Los Angeles May 1970, pp. 21, 35.

Comparison of historical cordon count data indicates that initial development of the regional freeway system consisted primarily of routes adjoining the downtown area and extension of these radial routes to the outlying suburbs. The trend of decreasing 16-hour vehicular traffic volumes crossing the cordon boundaries (starting after 1957 when historical peaks were reached) was primarily the result of the diversion of non-downtown oriented trips to the expanding freeway network.

Table 3-4

"BEFORE" AND "AFTER" SPEEDS FOR SIGNAL PROGRESSION EXPERIMENTS IN NEWARK, NEW JERSEY

Experiment Number	Direction	Peak Period	Speed in MPH		
			Before	After	Change
B100	North[1]	PM	8.9	14.3	+5.4
	South[2]	PM	9.9	8.4	-1.5
B93	North[2]	PM	15.7	13.6	-2.1
	South[1]	PM	12.8	16.7	+3.9

Source: Highway Research Board, National Cooperative Highway Research Program Report 113, Optimizing Flow on Existing Street Networks (Washington, D. C.: National Academy of Sciences-National Academy of Engineering, 1971).

1. Predominant Direction of Flow.

2. Minor Direction of Flow.

Examination of Table 3-4 shows that for experiment number B100 northbound traffic speed increased by about 61 percent, while for southbound motorists speed fell by about 15 percent. In this case, the fact that the southbound direction was the minor direction of flow (i.e., the lower volume of traffic) meant that time losses to southbound motorists were offset by large gains to northbound drivers. Trade-offs such as these must be evaluated for the entire street network including facilities on which no changes may be feasible.

Despite the difficulties of developing network "averages" of the impact on speed from implementation of various traffic flow techniques, an effort has been made for purposes of this study to evaluate the evidence and estimate the relative orders of magnitude of speed impacts which might be expected. Recent comprehensive research carried out under sponsorship of the National Cooperative Highway Research Program provided the major source of information.[1] The project provided information based on actually demonstrated methods of improving traffic flow on complex networks of city streets as compared with the usual information available for only spot or arterial improvement.[2] Dozens of traffic engineering improvements were implemented and evaluated in Newark, N.J. and Louisville, Kentucky. A network analysis was conducted to evaluate various models for use in the analysis of downtown area traffic flows. Work of the NCHRP study represents one of the most comprehensive efforts to evaluate the impact of various traffic engineering techniques and provided the major source for evaluating the magnitude of the impact of major traffic control improvements on speed.[1]

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[1] Highway Research Board, National Cooperative Highway Research Program Report 113, Optimizing Flow on Existing Street Networks (Washington, D.C.: National Academy of Sciences-National Academy of Engineering, 1971), p. 3.

[2] The project actually evaluated the means for better implementation and application of operational control strategies, data collection, system surveillance, etc.

Analysis of Recent Research

The experiments undertaken in Newark and Louisville were reviewed and all observations in which there were positive increases in speed were assembled. Table 3-5 summarizes the result of that analysis.

Forty-three observations in which there were speed increases were analyzed, and the percentage change in speed for "Before" and "After" conditions were calculated. For the purposes of analysis, only those observations which resulted in favorable results (i.e., positive increases in speed) were utilized.[2] Frequency distributions were prepared of the percentage changes in speed and the actual "Before" and "After" speeds.

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[1] The only approach not evaluated in the NCHRP project was the use of computer-controlled traffic and electronic guidance (which was considered beyond the scope of their study). However, our own discussions with traffic engineers and specialists in computerized control traffic indicate that any additional improvement as a result of computerized control would fall within the upper bounds of our estimates of speed changes in this chapter.

[2] Traffic flow control experiments with negative speed results were not taken into account. It was assumed that any speed losses which were not offset by substantial gains in dominant traffic streams would not be continued. In addition, our purpose was primarily to show the upper bounds of emission reductions which would be possible with successful traffic control and flow techniques. The possibility that some "improvements" may actually reduce speeds, however, should be kept clearly in mind.

Table 3-5
(page 1 of 2)

SPEED CHANGES FROM TRAFFIC CONTROL EXPERIMENTS IN LOUISVILLE, KENTUCKY, & NEWARK, NEW JERSEY

Experiment Type & Number	Direction	Time	Travel Speed (MPH) Before	After	Percent Change	Ref.
Signal Progression:						
B 100 - Newark	NB[1]	PM	8.9	14.3	60.7	Tables 17 & 20, pp. 66 & 69, G-136, p. 323
	SB	AM	12.3	18.2[1]	48.0	
B 93 - Newark	NB[1]	PM	7.4	16.4	121.6	
	SE[2]	PM	12.6	14.2	12.7	
	SB[1]	PM	12.8	16.7	30.5	
	NB	AM	12.7	14.5	14.2	
	SB	AM	13.1	15.3	16.8	
B 88 - Newark	EB[1]	AM	11.0	15.9	44.5	Table G-111, p. 299
	WB[1]	PM	9.0	12.0	33.3	
	EB	AM	11.1	19.1	72.1	Table G-112, p. 300
	EB	PM	11.2	12.3	9.8	
	WB	PM	9.8	12.7	29.6	
One-Way Streets: Speed & Delay Analysis						
E 30 - Louisville Mellwood Ave.	EB	AM	16.6	20.2	21.7	Table G-1, p. 156
	EB	PM	17.3	20.6	19.1	
	EB	All	16.9	20.4	20.7	
Story Ave.	EB	PM	18.1	20.6	13.8	
	EB	All	19.5	20.4	4.6	
	WB	AM	18.2	27.3	50.0	
	WB	PM	21.2	26.9	26.9	
	WB	All	19.7	27.1	37.6	
All Directions & Streets	All	AM	17.2	23.8	38.4	
	All	PM	17.5	23.8	36.0	
	All	All	17.4	23.8	36.8	
Directional Control & Lane Use: Speed & Delay Runs						
E 31 - Louisville	NB	AM	10.9	19.4	78.0	Table G-3, p.161
	NB	PM	10.7	17.9	67.3	
	SB	PM	15.3	16.8	9.8	
	All	All	13.8	17.2	24.6	Table G-11, p. 162

1. Predominant direction of flow
2. Minor direction of flow

Table 3-5
(page 2 of 2)

Experiment Type & Number	Direction	Time	Travel Speed (MPH)		Percent Change	Ref.
			Before	After		
Reversible Lanes:						
B 78 - Newark	SB	AM	8.2[1]	12.2[1]	48.8	Table G-9, p. 125, p.18, Tables 22-3
Lane Markings:						
B 86 - Newark	EB	AM	13.7	15.7	14.6	Table G-14, p. 182
	WB	AM	17.6	18.8	6.8	
Left Turn & Pedestrian Controls:						
A 7 - Newark	EB	AM	6.5	10.9	67.7	Table G-32, p. 211
	WB	AM	9.9	12.0	21.2	
	SB	AM	12.8	14.3	11.7	
	WB	PM	5.5	6.5	18.2	Table G-33, p. 212
Truck Loading Restrictions:						
C 123 - Newark	Segment 1	All	4.0[1]	5.5[1]	37.5	Table G-34, p. 217
Channelization:						
A 33 - Newark	WB	AM	8.6[1]	11.0[1]	27.9	Table G-44, p. 238
D 68 - Louisville	Speed & Delay	AM	24.5[1]	25.0[1]	2.0	Table G-74, p.263
Network Signal Coordination:						
E 35 · Louisville	EB	AM	19.2	21.1	9.9	Table G-154, p. 346
	WB	AM	14.3	15.5	8.4	
	Avge.	AM	16.7	18.3	9.6	do.
	EB	PM	14.4	17.9	24.3	Table G-155, p. 346
	Avge.	PM	14.4	14.5	0.7	
	Avge.	AM	17.7	18.0	1.7	Table G-156, p. 347
	Average (Mean)		13.7	17.2	25.5	

Source: Highway Research Board, Optimizing Flow on Existing Street Networks, National Cooperative Highway Research Program Report 113 (Washington, D.C.: National Academy of Sciences-National Academy of Engineering, 1971).

[1] Estimated using calculated Delay Ratios and Delay Ratio-Travel Speed Curve.

The frequency distributions were then plotted, as shown in Figures 3-3 and 3-4.

In terms of the percentage changes in speed resulting from these experiments, Figure 3-3 shows that about 67 percent of the observations fell within the class interval ranges of 5-10 percent and 35-40 percent. Though the distribution of speed changes is statistically skewed, it would appear from data in Figure 3-3 that the best range for expected speed change from similar experiments (on a network basis) would be represented by values between these two class intervals (which account for almost 70 percent of the observations) The arithmetic mean for 42 of the observations was 27.8 mph.[1] The median percentage change was 28.5 percent.

Based on "Before" and "After" speeds, frequency distributions were also prepared for the 43 experiments (Figure 3-4) and the median speed for "Before" and "After" conditions calculated. These calculations indicate that the median speed for "Before" conditions was 13.6 mph. and for "After" conditions was 17.3 mph. The increase from 13.6 to 17.3 mph. represents a 27.2 percent increase and compared closely to the mean and median percentage changes shown in Figure 3-3. Calculation of the mean "Before" and "After" speeds showed a very similar range of change of 25.6 percent (Figure 3-4).

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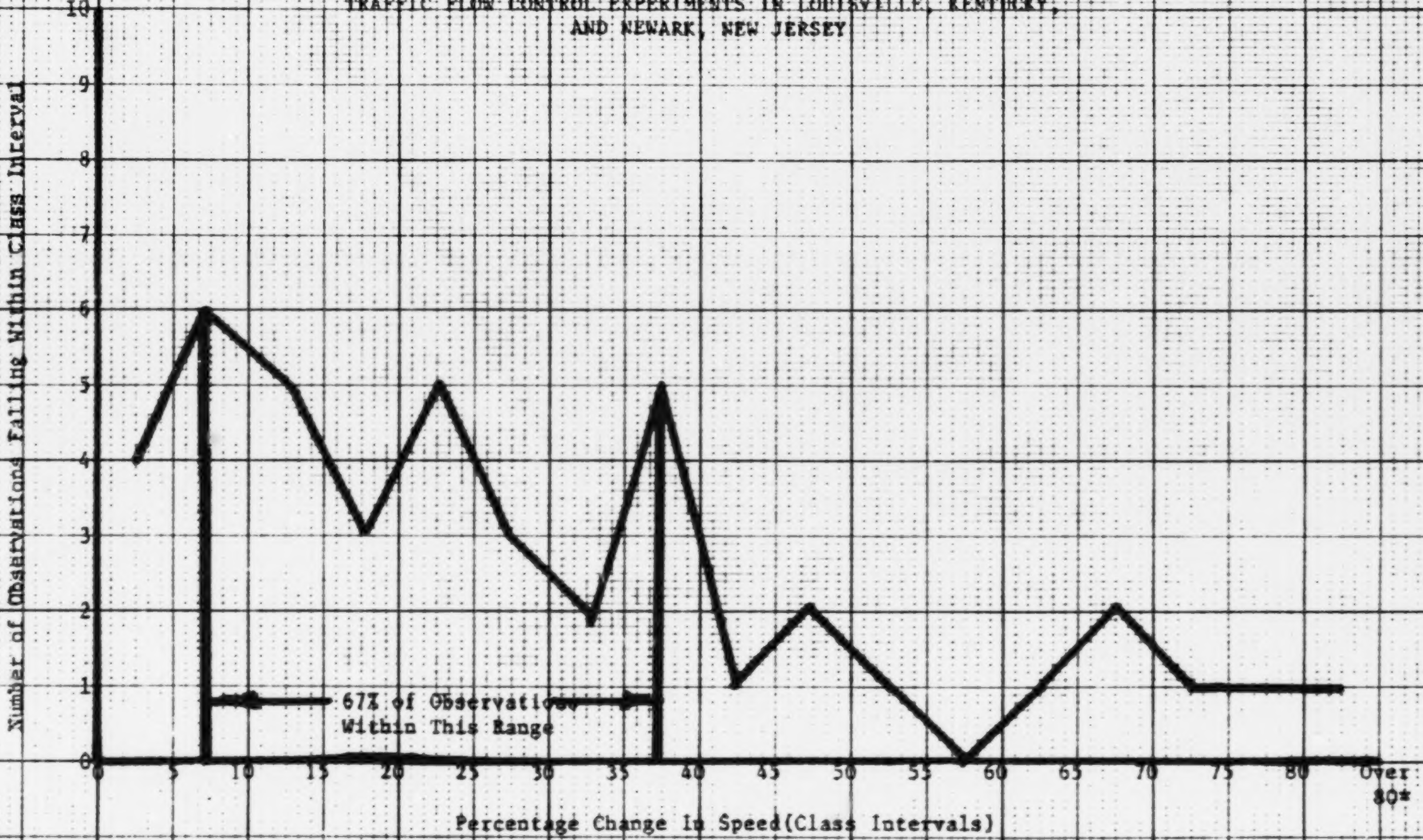
1. Because it was an extreme value, the speed change of 121.6 percent was dropped for calculation of the arithmetic mean. It is, however, shown in Figure 3-3 in the class interval 80 and over. It was not excluded for calculation of the median because it does not affect the median value significantly.

Figure 3-3

FREQUENCY DISTRIBUTION OF PERCENTAGE CHANGE IN SPEED FROM TRAFFIC FLOW CONTROL EXPERIMENTS IN LOUISVILLE, KENTUCKY, AND NEWARK, NEW JERSEY

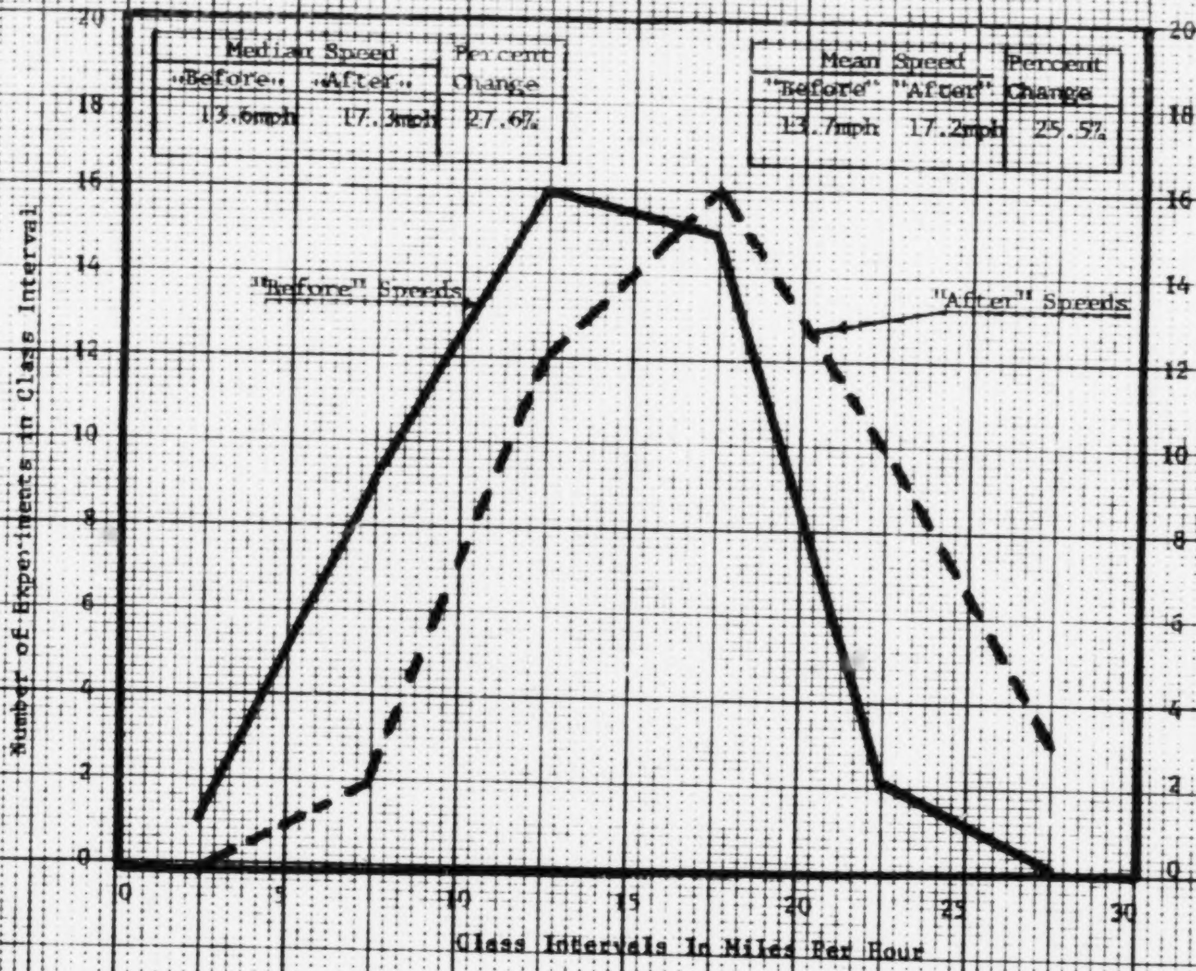


*One observation(121.6%) in the class interval 80 or over

Source:Highway Research Board,National Cooperative Highway Research Report 113,1971.

Figure 3-4

FREQUENCY DISTRIBUTION OF PERCENTAGE CHANGE IN SPEED FROM TRAFFIC FLOW CONTROL EXPERIMENTS IN LOUISVILLE, KENTUCKY, AND NEWARK, NEW JERSEY



Source: Highway Research Board, National Cooperative Research Program, Report 113, 1971.

Application to Six Target Cities

It was recognized for the purpose of the present study, of course, that the experience in Newark and Louisville would not be precisely comparable to data which might be developed for San Francisco, Los Angeles, Chicago, Washington, D.C., New York and Denver. However, the traffic control techniques used in Newark and Louisville were comprehensive and encompassed the most promising approaches presently available (short of using computers to help implement these controls more efficiently). Based on this data, in conjunction with experience elsewhere and traffic engineering judgment, the upper and lower bounds of network impacts which might be expected from implementation of traffic flow techniques was estimated. Using the class interval range accounting for 67 percent of the observations as the boundaries, a low, high and intermediate speed impact developed (Table 3-6). Thus, the mid-point of the lower and upper class

Table 3-6

RANGE OF EXPECTED CHANGES IN SPEED FROM
TRAFFIC FLOW IMPROVEMENTS

	Percentage Change in Speed	
Boundary	Mid-point	Rounded Value
Low	7.5	10
Intermediate	27.5	30
Maximum	37.5	40

intervals were rounded to 10 and 40 percent, respectively. The intermediate value was based on the "Before" and "After" mean and median calculations (Figure 3-4) rounded to 30 percent.

Maximum Feasible Emission Reduction

In considering the effect of these percentage changes on speed (and therefore emissions), the most important consideration concerns the initial baseline speed. There are significant differences for both traffic engineering and pollution control, depending on whether baseline speeds are, say, 10 mph or 25 mph. For example, for pre-1968 vehicles, an increase in speed from 10 to 15 mph will result in carbon monoxide emission reductions on the order of about 29 percent, whereas increases in speed from 25 to 30 mph will result in emission reductions on the order of only 15 percent.[1] Moreover, it must be remembered that speed improvements could be short lived (about two to four years according to available evidence). Finally, implementation of traffic flow techniques in the absence of other controls may actually *increase* motor vehicle emissions (i.e., if average vehicle speeds dropped to their former level but traffic *volumes* increased, motor vehicle emissions would be worse).

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[1] These estimates are based on a preliminary EPA graph of carbon monoxide adjustment factors as a function of speed. See M. J. McGraw and R. L. Duprey, "Compilation of Air Pollutant Emission Factors" (preliminary document, U.S. Environmental Protection Agency, April 1971). The data used to derive this graph were obtained from pre-controlled vehicles. See Appendix C for a discussion of the speed-emission relationship.

Institutional Feasibility

In many ways, most traffic flow techniques are relatively easy to implement.[1] Most large cities are staffed (though not always adequately) with competent traffic engineers, and have the administrative capability to implement and enforce a traffic flow improvement program. A great many cities also have prepared comprehensive traffic improvement plans, for which only funding is now required.

Federal funding for such programs is currently possible through the TOPICS (Traffic Operations Program to Increase Capacity and Safety) program. The purpose of TOPICS is to assist urban areas in obtaining the maximum efficiency and safety from existing urban streets through a systematic application of traffic engineering techniques. TOPICS improvements are usually accomplished without right-of-way acquisition and do not normally involve major construction efforts but rather the application of more sophisticated signal control, parking restrictions, lane widening, turn lane additions, channelization and other traffic engineering techniques. Air pollution control, of course, is not one of the objectives of this program, but it could occur as an important by-product of improved traffic flow. Major federal funds have been available for the TOPICS program only since January 1969, and as of mid-1971, a total of $116,391,159 had been approved to finance programs. New and broader programs would require increased funding. Certainly, support from EPA for new programs would be

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1. Probably the primary exception to this generalization concerns the prohibition of on-street parking, a measure which is usually opposed by local merchants and other area residents. This measure will be examined in greater detail in Chapter 6, "Motor Vehicle Restraints."

welcomed by the Department of Transportation, especially the Federal Highway Administration which administers the TOPICS program. However, in view of our earlier discussion as to potential traffic growth and the transient nature of these improvements, their intermediate and long-run consequences should be very carefully considered.

The investment required for a major program of traffic flow improvements (including freeway surveillance and computer control of city street signal systems) would be very large. Conversation with State highway planners in Los Angeles indicated that there is a comprehensive plan for implementing "basic" improvements for traffic surveillance and control with an estimated ten year cost of about $120 million, or about $10 million a year. Implementing network-wide traffic flow control programs of the magnitude implied by this chapter's discussion could require annual funding at least two to three times that level.[1]

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[1] Even the research required for these programs is extremely expensive. For example, in a recent appraisal of freeway control and ramp control, research needs were estimated to be about $7 million for roughly a three to five year program. See Highway Research Board, National Cooperative Highway Research Program Report 84, Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Washington, D. C.: National Academy of Sciences-National Academy of Engineering, 1970), Table 1, p. 21.

CHAPTER 4

BYPASSING THRU TRAFFIC

Definition of Terms

In most urban areas there is a relatively large proportion of motor vehicle traffic with no need to pass through the center of the city. Two components of this "thru traffic" can be identified: (1) inter-urban "thru" traffic traveling long distances with no need to pass through any part of the city, and (2) intra-urban "thru" traffic with origins and destinations usually located on the periphery of the city (or at least not within the heavily congested core).[1]

Traditionally, traffic engineers have tried to separate thru vehicles from traffic with origins and destinations within the core area of the city in order to alleviate downtown traffic and transport problems. To this end, several measures are available to divert motorists who would otherwise pass thru downtown areas. In this chapter, we examine these measures (e.g., use of circumferential routes such as beltways, directive signs and signals) as well as some recently proposed possibilities (e.g., physical barriers in the central business districts combined with beltways) which have emerged as a result of recent efforts to deal with air pollution.

Circumferential Routes (Beltways)

One of the most widely used methods for bypassing thru traffic is by use of grade-separated controlled-access routes which circle the city.

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[1] Unless otherwise stated, we use "thru traffic" to refer to both travel components. The distinction is important, depending upon whether the entire metropolitan area, the central cities therein, or just the downtown districts are under consideration.

Often called "beltways," they are usually planned so as to be placed in the first large band of uninhabited land just beyond the city limits or built-up suburban residential areas. Circumferential routes act both to bypass traffic with inter-urban origins and destinations and to distribute intra-urban traffic.[1] Beltways, for example, provide an almost ideal site for the performance of truck-to-rail transfers, particularly at points of intersection with rail facilities.

As a result of the interstate highway construction program, most large cities now have some form of circumferential facility; many of these, however, are not completed or fragmentary in nature. In some cities (e.g., Los Angeles and New York), beltways do not take on a circular character, whereas in others (e.g., Washington, D.C.) they literally circle the entire central city.[2]

Inner Loops

In addition to circumferential facilities located just beyond city limits, some central cities are served by "inner loops" situated at the outer edges of the downtown district or slightly beyond. Such facilities function primarily as distributors for traffic moving in and out of the CBD. Osaka, Japan, for example, has a loop which circles the edges of the CBD, and permits traffic to move quickly around the CBD and avoid congested city streets. To the extent that traffic moves rapidly on an inner loop, trips tend to be diverted away from city streets; crosstown traffic using city streets (and their associated at-grade stop lights, intersections, stop signs and delays) also tends to be be reduced.

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[1] Particularly where no "inner loops" exist, beltways may serve primarily to distribute traffic from the suburbs (i.e., intra-urban travel) along major arterials leading downtown. This has been the case for the Washington, D.C. beltway, somewhat to the surprise of transportation planners who ex- trips by facilitating high speed north-south movement. See, National Capital Region Transportation Planning Board, Impact of the Capital Beltway: Some Notes and Observations, Information Report No. 13 (Washington, D.C.: Council of Governments, November 1968), pp. 5ff.

[2] Central cities, usually defined as those areas within the incorporated limits of the major city in a given metropolitan area, are distinguished from the central business district (CBD), which generally refers to the high-density, commercial and business cores of cities. Exact definitions of central business districts vary, of course, with some jurisdictions having more than one CBD.

Directive Signs and Signals

Especially where circumferential facilities are not available, directive signs and/or signals are often used as a means of encouraging traffic to bypass the CBD. In many cities, bypasses are identified by special signs as recommended routes to be used to avoid congested areas.

Restrictions by weight and/or time of day may be placed on vehicle movements along specific arteries, especially those expected to be congested during peak hours. For example, trucks may be prohibited on certain routes passing thru the CBD by designating special truck routes, so as to either divert heavy trucks to higher-load bearing roadways or to prevent their mingling with passenger vehicles during the most congested period of the day.

Special Stickers

Another means to divert thru traffic would be through use of special stickers, which could be color-coded as to specific route and perhaps time of day. Drivers without special stickers would be required to use only bypass routes. Thus, if a driver wished direct access to the CBD, the sticker would permit him to use appropriate arterials and connector streets. To the best of our knowledge, special stickers for the above purpose have not been tried.

An additional possibility would be to use tolls.[1] Thru routes, for instance, could be made toll-free in order to encourage their utilization. However, if such toll-free bypass segments are to significantly attract thru traffic, the toll portions would have to have substantially higher rates to begin with than is presently the case.

Bypass Combined with Motor Vehicle Restraints

As indicated in Chapter 6 ("Motor Vehicle Restraints"), a number of measures could be applied to reduce motor vehicle use in central cities. Combining these measures with bypass facilities could result in substantial reductions in motor vehicle emissions.

An important example of this technique was implemented in Gothenburg, Sweden in 1970[2]. The city's CBD was divided into wedge-shaped quadrants.

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1. Among the large cities with toll facilities on major entry points of high capacity highways leading into the city are Boston, New York, Philadelphia, Baltimore, Chicago, Kansas City, Jacksonville and Miami. However, these facilities are universally used to raise revenues, not to control motor vehicle traffic.

2. Traffic restrictions were initially instigated in Gothenburg at the urging of various public officials concerned with the severe traffic congestion developing during pre-Christmas shopping hours. The chief of the fire brigade was concerned with difficulties in gaining access to CBD areas for fire equipment. Officials involved with traffic accidents, public transit, and air and noise pollution also supported traffic restrictions. For further discussion of the planning and implementation of Gothenburg's traffic restraint scheme, see Curt M. Elmberg, "The Gothenburg Traffic Restraint Scheme" (Paris: Organization for Economic Cooperation and Development, May 1971). (Mimeographed.)

Physical barriers[1] were constructed between these quadrants, thus making traffic through the CBD impossible (except to emergency vehicles such as fire or ambulance and public transit which are permitted to pass. In effect, each quadrant became a self-contained precinct with only local circulation allowed. All other traffic was required to use a ring road (similar to the inner loop facilities discussed above), entering and leaving each quadrant at designated locations. For a schematic representation of the Gothenburg scheme, see Figure 4-1.

The success of the barriers in decreasing thru traffic in Gothenburg can be clearly seen. After eight weeks of operation, traffic on one of the main arterials (Östra Hamngatan) was decreased by some 70 percent. As Figure 4-1 shows, traffic has shifted to the peripheral streets.

Barriers have not been used in large scale anywhere in the United States as yet. The size of the experiment in Gothenburg (whose population numbered slightly more than 444,000 in 1971) does not provide adequate evidence that a similar strategy can be easily and quickly transferred to any major United States city. Particularly for the six cities under study for this project, the size and extent of motor vehicle ownership make it

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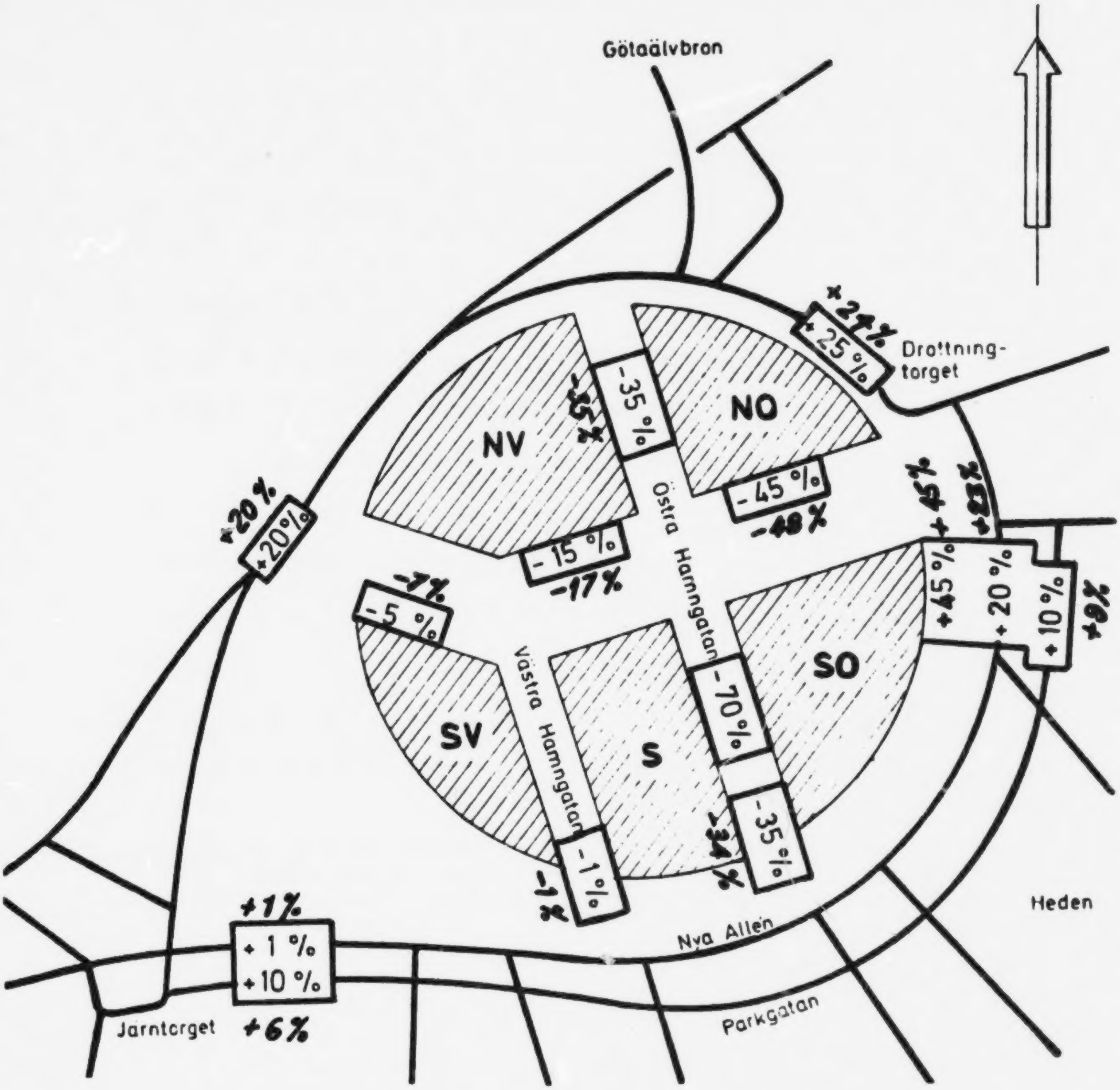
1. Physical barriers consisted of movable concrete "curbing" in sections approximately one foot high and three feet wide. In some cases large directional signs were mounted onto curb sections to indicate traffic direction at critical points.

Figure 4-1

SCHEMATIC REPRESENTATION OF GOTHENBURG, SWEDEN TRAFFIC RESTRAINT SYSTEM


Götaälvbron
+27%
+25%
Drottningtorget
-35%
-35%
NV
NO
-45%
-40%
+20%
+20%
-15%
-17%
-7%
-5%
Östra Hamngatan
Västra Hamngatan
+45%
+45%
+23%
+20%
+10%
+8%
SV
S
SO
-70%
-35%
-34%
-1%
-1%
Heden
+1%
+1%
+10%
+6%
Nya Allén
Parkgatan
Jarntorget

Source: Curt M. Elmberg, "The Gothenburg Traffic Restraint Scheme" (Paris: Organization for Economic Cooperation and Development, May 1971), p. 22.

Note: Hatched areas are quadrants; lines represent major arterials. Numbers refer to percentage change in vehicle volumes along central area routes two weeks and eight weeks (figures in boxes) following introduction of scheme in August 18, 1970.

doubtful that a similar experiment could be implemented before at least two or three years of planning.[1]

Two observations appear warranted from the Gothenburg experiment. First, it would seem unlikely that the use of barriers provides for any major reductions in area-wide vehicle miles traveled. However, the Gothenburg approach does appear useful in providing for some redistribution of emissions from downtown districts already saturated to peripheral areas with less pollution. To the extent that average vehicle speeds could be increased, of course, motor vehicle emissions would also be reduced.

Second, the Gothenburg experiment seems to suggest the necessity of a circumferential route (e.g., an inner loop) relatively close to the restricted area. Thus, in cities such as Washington, D.C. (where beltways have been built just beyond city limits) the use of barriers on a broad scale would appear to require construction of a circumferential facility much closer to the CBD. Within the short term (i.e., five years) implementation of a major effort is probably not feasible for any of the six cities under study for this project. However, smaller-scale use of motor vehicle restraints and existing arterials to redistribute traffic away from specific critical locations may be possible.

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[1] Even the comparatively small Gothenburg experiment entailed a planning period of seven years. Once the plans were finalized, preparatory work included reconstruction of certain intersections on peripheral routes to accommodate increased traffic loads, relocation of tram stops, route signing, street painting, the placement of physical barriers and informational advertising. See, Curt M. Elmberg, "The Gothenburg Traffic Restraint Scheme" (Paris: Organization for Economic Cooperation and Development, May 1971). (Mimeographed.)

Air Pollution Control Potential

Data to determine the extent of thru traffic (as the term is used here) are difficult to come by.[1] The extent of thru traffic will vary from city to city, depending on the inclusiveness of the term (e.g., intra-urban traffic, inter-urban traffic, vehicles not parking), the time period considered (e.g., peak or all day) and the area of study (e.g., metropolitan region, the central city or CBD), as well as the travel patterns of the particular area.

Nevertheless, it appears from available data that in the central cities of many American metropolitan areas, thru traffic can account for a substantial share of total traffic volumes, even at peak hours:

1. The Buffalo Board of Safety estimates that between 60 and 70 percent of all vehicles passing thru the downtown area have neither origins or destinations there.

2. In the downtown Milwaukee plan, the authors state: "Finally, the whole traffic problem in the central business district is aggravated by a serious conflict between local and thru traffic. It is estimated that around 70 percent of the vehicles entering the CBD have destinations there and the remaining 30 percent are merely passing through."

3. In New Orleans, it was determined that "the 71,891 vehicles passing thru the central business district without parking comprised about 78 percent of the in-bound traffic between 10:00 a.m. and 6:00 p.m. on an average 1960 weekday."

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[1] In some areas, different concepts (e.g., that of "external trips," because at least one end of the trip is outside the area of analysis) are used by transportation planners. In virtually all cases, however, data about travel are obtained by interviewing a sample of drivers crossing a given cordon line, which could be drawn around the metropolitan area, the central city or downtown districts. How each of these areas is defined, in turn, can also vary from area to area.

4. In Atlanta, the daily number of persons passing thru, as against those destined for the CBD were found to be roughly equal in cordon counts performed in 1941, 1945, and 1948; furthermore, a count in 1953 revealed that the number just passing thru had risen to 57 percent of the total.

5. In Detroit, 25 percent of the evening traffic of about 73,000 person-trips consists of thru trips; of the 18,200 thru trips, 6,800 are thru transit trips.[1] As suggested by these data there appears to be considerable variation in thru traffic from city to city.[2]

The above data, it should also be noted, are somewhat out of date, and for medium-sized cities only. More recent information for the CBD's of large U.S. cities is difficult to come by[3] but it appears that thru traffic probably accounts for no more than a third of total traffic in these areas.[4] If the central city as a whole is considered, the proportion of bypassable traffic would be even less,[1] about 5 to 20 percent of total traffic approaching most medium-and large-sized cities according to one estimate.[2]

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[1] Based upon special CBD traffic study and cordon counts, cited in J. R. Meyer, J. F. Kain, and M. Wohl, The Urban Transportation Problem (Cambridge, Mass.: Harvard University Press, 1965) p. 87.

[2] From an air pollution point of view it is particularly important to distinguish between thru person-trips and thru motor vehicle trips. The latter probably account for a disproportionately large share of vehicle miles traveled, since thru trips tend to be longer than other categories.

[3] In most cases, obtaining such data would require special surveys on a city-by-city basis.

[4] This proportion probably tends to increase in the medium-sized and smaller cities, although much obviously depends upon the area's highway and street system and location vis-a-vis major inter-state routes. Cities located at major junctions along east-west and/or north-south routes (e.g., Chicago or Indianapolis) tend to have a higher proportion of thru traffic than those situated at route terminations (e.g., coastal cities such as San Francisco).

From an air pollution control viewpoint, bypassing thru traffic would (1) shift vehicle miles traveled away from already congested central city roadways and (2) smooth traffic flows by a separation of thru and local traffic in the areas affected. Hence, the air pollution control potential of bypassing thru traffic is multiple in effect; both of the above results would reduce emissions downtown, the first by redistributing vehicle miles traveled (and hence emissions) elsewhere, and the second by bringing about higher average vehicle speeds and fewer stops and starts and idling (and the emission reductions associated with these improvements).

Air pollution control potential of better bypass facilities alone, however, is currently limited by a number of factors. First, as noted above, beltways (and in some cases inner loops) already serve most major U.S. metropolitan areas. In the short term there is little doubt that these facilities do reduce congestion (and emissions) by diverting thru trips and improving traffic flow.[3] There is little reason, however, to think that significantly more traffic could be attracted than is currently the case, except by imposing motor vehicle restraints on the street system of the city itself.

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[1] How much less would depend upon the relative contribution of inter-urban and intra-urban traffic (the latter consists of trips whose origins or destinations are usually within city limits).

[2] National Capital Region Transportation Planning Board, Current Planning on the Outer Beltway, Information Report No. 14 (Washington, D.C.: Council of Governments, December 1968), p. 5

[3] In the medium and long term, however, more and longer trips may result from the highway improvement and the dispersed residential development it generates.

Second, most measures (again, excepting motor vehicle restraints) designed to divert thru traffic depend upon the voluntary compliance of drivers, and thus upon the relative attractiveness of traffic conditions on bypass routes as compared to the city street system. However, to the extent that traffic grows to fill the capacity of circumferential routes (as is commonly the case), conditions along these routes are no more attractive than on city streets, drivers are not diverted, and even in the short-term motor vehicle emissions are not appreciably reduced. Again, however, much depends upon the annual traffic growth in the area, especially, as noted in the previous chapter, the extent to which the existing city streets are "saturated" with traffic. In the long-term, construction of circumferential routes tends to encourage residential and commercial development along the alignment and/or within easy access. This, in turn, tends to further population dispersion, increase average trip lengths, and result in greater motor vehicle use.[1]

Use of directive signs and signals is also dependent upon the voluntary compliance of drivers, since, except for commercial traffic, bypass routes marked by such signs and signals are optional in most areas of the

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[1] For example, since the Washington, D.C. beltway was completed in the mid-1960's, auto commuting trips are up sharply, both in absolute numbers and in proportion to total trips. And, "while commuting to the District of Columbia is forecast to increase by 83 percent over 1960 levels by 1976, circumferential travel increases of between 104 and 610 percent are expected." National Capital Region Transportation Planning Board, "Travel Demand for the Outer Beltway" (Washington, D. C.: Council of Governments (undated). (Mimeographed.)

United States. For this reason, directive signs and signals are infrequently followed, particularly where vehicle operators are familiar with the area. Drivers unfamiliar with the area (i.e., most inter-urban thru traffic) are more likely to use optional bypass routes, but the fact that such routes are optional means they are unlikely to divert drivers, especially if the alternate routes are not grade-separated and/or controlled access. Significant diversion of thru traffic, therefore, will probably require some form of motor vehicle restraints (see Chapter 6) in the downtown areas of the central city.

Maximum Feasible Emission Reduction

The two principal possibilities for bypassing thru traffic are the use of circumferential routes (e.g., beltways) and directive signs or signals. To the extent that these measures depend upon new construction,[1] they cannot be implemented within the next five years. To the extent that other measures are available and designed specifically to attract and divert thru vehicles, some limited reductions may occur.

Data are not available to permit exact estimates as to the emission reduction potential of these measures. However, in our best judgment the reductions which could be achieved in the short-term from bypassing thru traffic would be unlikely to exceed 5 percent in most central cities. Greater reductions might be possible in some CBD's, particularly if measures to bypass traffic were combined with motor vehicle restraints (see Chapter 6). Evaluation of the multiple effect of these measures (i.e., taking into account increases in vehicle speed) is not possible without computer simulation, which is beyond the scope of this project.

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[1] For some simple construction activities, some improvements might be possible. For example, special ramps or very short segments of connecting arterials to provide for bypass linkages could be built to provide for some bypassing. These possibilities would have to be specifically identified for the purposes of study.

Institutional Feasibility

As noted in the discussion on traffic controls, construction of major highway facilities including circumferential routes is not likely to be feasible within the time limits of 1977. In urban areas where circumferential facilities are already under construction, some bypassing of through traffic might be possible by 1977, but where no plans exist, at least eight to ten years would be required. Even with an accelerated effort, it is unlikely that major construction of circumferential facilities could be achieved in less than five to eight years.

CHAPTER 5

IMPROVEMENTS IN PUBLIC TRANSPORTATION

Definition of Terms

In the present chapter, we consider mass transit as conventionally defined (rail and bus systems) as well as a number of other means of conveyance such as the taxi, demand responsive systems, car pools and people movers. Conceivably, improvements in public transportation could reduce motor vehicle emissions in the short run, by attracting motorists away from their automobiles, and in the long run by encouraging high density development and more efficient land-use.

In the paragraphs which follow, we will review the opportunities for public transport improvements over the short (i.e., five-year) term. In subsequent sections ("Air Pollution Control Potential" and "Maximum Feasible Emission Reductions"), we examine the potential of these improvements for reducing motor vehicle emissions. The final section ("Institutional Feasibility"), considers the principal institutional problems associated with implementing the most important candidates.

Before proceeding, however, a caveat is in order concerning the role of public transport improvements in the context of air pollution control. Extensive review of all recent evidence leads us to conclude that public transport improvements alone hold out little promise for major modal diversions, much less for reductions in motor vehicle emissions. Public transport improvements, in other words, are a necessary but not sufficient condition for reducing motor vehicle emissions. Reducing emissions would require other measures (e.g., parking controls, auto free zones[1]) to restrict or restrain motor vehicle use. But for these measures to be feasible, public transport must be improved. Consequently (and although it is treated independently in this chapter), public transport for purposes of air pollution control should be considered only as complementary to a larger control strategy (i.e., one consisting of motor vehicle restraints and other measures discussed in this report). Public transport must play a useful role, although it cannot by itself be relied upon to reduce emissions.

Rapid Transit Systems

By rapid transit systems we refer to grade-separated rapid rail systems (other than busways) which are particularly suited for line-haul high density corridors in heavily populated areas.[2] Passenger capacities of these systems range from 30,000 to 60,000 persons per hour for each track. Traditionally, grade-separated rapid rail transit has involved higher initial capital construction cost than highways. In urban areas, however, the construction cost differentials between road and rail systems seem to be disappearing.[1]

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[1] See Chapter 6, "Motor Vehicle Restraints." Without these measures, public transport improvements (particularly rapid rail) may cause motor vehicle emissions to increase over the long-run where they are currently worse (i. e., in the downtown or other densely developed districts).

[2] Only five metropolitan areas in the United States presently have rapid rail systems: New York, Chicago, Boston, Philadelphia, and Cleveland. Two other areas (San Francisco and Washington, D. C.) have rapid rail systems under construction. Pittsburgh, Baltimore, Buffalo, Atlanta, St. Louis, Minneapolis-St. Paul, Miami, Detroit, Dallas, Denver and Honolulu are presently in various stages of planning rail systems. Even Los Angeles, probably the example par excellence of an auto dominant city, is currently considering a proposal by the Southern California Rapid Transit District to construct a $420 million subway-elevated line to run 14 miles from the city's downtown into Watts.

Construction of new systems. Historically, the gestation periods for new rail systems have been very long in the United States. Corridor studies, pre-feasibility studies, feasibility studies and final designs must all be undertaken. Months or even years may be necessary merely to acquire rights-of-way because of legal, technical and political difficulties. Even after land is acquired, delays may arise due to difficulties in obtaining financing and political acceptance and the time-consuming construction of facilities. In San Francisco, for example, preliminary studies for the Bay Area Rapid Transit System (BART) date back to at least the mid-1950's and a minimum construction period of ten years is anticipated. Similarly, the first study for the Washington, D.C., Metro was begun in 1955 and completed in 1958. Ground was not turned for construction until late 1969, and the entire network (some 90 plus miles) will not be completed until at least the end of this decade.

Given these long gestation times, ten years would seem optimistic for opening even the first short stretches of line. Certainly, no rapid rail system which is not currently under construction or in the final design stages of engineering, could be expected to be open for its first service within five years. Among the six metropolitan areas examined in this study, only San Francisco's BART and Washington's Metro could be open for service within the next five years.[1]

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[1] In urban areas of the United States (where right-of-way acquisition is most expensive), the cost of constructing urban highways ranges from $10 to $40 million per mile (for depressed freeways and complex interchanges these costs are higher), while for rail, the estimated per mile construction costs for San Francisco's BART and Washington, D.C.'s Metro are $17.5 and $30.4 million, respectively. Costs, of course, vary somewhat from city to city depending upon local wage rates, soil conditions and climate, and the penchant of City Fathers for elaborate construction and rich furnishings.

Over an eight- to ten-year period (i.e., beyond the time frame of this study), it may be reasonable to expect improvements in the construction techniques for tunnels and underground stations (e.g., better boring equipment, improved techniques for excavating earth and rock, increased use of prefabricated slabs, and so forth). If these or other improvements materialize, reductions in construction costs may be expected, which in turn could alter the relative attractiveness of tunneling rail transit systems through densely developed areas. These improvements might help compress total implementation time somewhat. However, since most of the delays are not technologically related, about eight years from initiation of the first study to opening of a first stretch of line seems to be about the best that can be hoped for under present conditions in any major metropolitan area.

Extensions of existing systems. Construction of extensions to existing rail transit systems appears somewhat more promising in the short-term, and could conceivably be carried out within four to six years, assuming a definite decision to proceed were taken now.[1] In addition to improved construction techniques, the speed with which such extensions can be initiated and completed depends upon a number of factors. These include the amount of planning and financial programming already completed, the extent to which final designs have been finished, the degree to which system specifications differ from those already in use and the amount of other rapid rail construction actually in progress in the area.[2]

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[1] Of those areas not considered for this study, Pittsburgh is probably the only major metropolitan area in the United States which has final designs nearly ready. (The Pittsburgh system is to utilize the Westinghouse Skybus, a train-like system that runs on rubber tires in a concrete guideway. An experimental version of the system has been operating in a Pittsburgh park since 1966.) A five-year time frame (i.e., by 1977) would similarly rule out contemplated rail systems in Atlanta, Baltimore and Buffalo.

Operational and service improvements. In addition to construction of new rail lines or extensions to existing systems, rail transit ridership could be increased by measures such as the following:

1. Reducing fares -- fare reductions to at least 25¢ in a base zone would probably do more than any other measure to increase rapid transit ridership. Only Boston has such fares at present. In all cases, fare reductions would require extensive, continuing subsidies to cover operating deficits. Commuter rail service would be a parallel case.

2. Increasing comfort, cleanliness and safety -- cleaning up stations, better lighting and more active policing would help (especially in cities such as New York and Chicago). However, most of these measures would cost far in excess of the additional patronage they would generate (e.g., reducing noise in the older rail systems and rehabilitating equipment would involve

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[1] Among cities currently working on extensions or major improvements to existing systems are New York City, where, in spite of the rejection at the polls last November (1971) of a $2.5 billion transportation bond issue, officials say there is still enough money left from the 1967 bond issue to start work on a new Second Avenue subway, and to continue links between Queens and several existing lines in midtown Manhattan; Philadelphia, where plans are set for expansion of the successful Lindenwold line from New Jersey; Boston, where a $124 million bond issue was authorized for improvements to the local system; and Chicago, which has requested $500 million from the Urban Mass Transportation Administration for two new subway lines.

[2] With other rapid rail construction going on in an area, knowledgeable contractors would be available with an incentive to negotiate quickly for additional work.

hundreds of millions of dollars in track renovation and car rebuilding for relatively modest increases in ridership).

3. Increasing service frequency -- this improvement is usually not important to rapid rail systems at peak hours, although some frequency increases during off-peak periods and on holidays and weekends could draw more ridership.[1]

4. Providing Park'n Ride -- free or low cost parking facilities at rapid rail stations could be an important factor in increasing patronage, particularly for commuter rail services.

5. Improving fare collection -- automation can speed passengers on their trips and make possible more flexible charges. Provision of monthly passes is another example, and has proven a popular convenience which can increase ridership on commuter lines.

Experimentation with extending and improving rail service, particularly suburban commuter rail lines, has achieved success in some instances.[2] However, in virtually all cases where improvements have been implemented it is apparent that no single improvement -- reduced fares, increased service frequency, or provision of park'n ride -- has been responsible in and of itself for any major increase in rail transit ridership. Probably the most successful combination of improvements in recent years has been the new Lindenwold line between southeastern New Jersey and Philadelphia. As detailed in Appendix E, riders were attracted to the Lindenwold line by a package of improvements -- free and available parking, travel time differentials, fast, reliable and comfortable service -- as well as disincentives to use the motor vehicle in terms of increased congestion and increased bridge tolls along the paralleling highways.

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[1] Any additional off-peak ridership, however, would probably not be drawn from motorists, who generally (except perhaps in New York) have little or no problem in moving about in their motor vehicles except at peak hours.

[2] Federal assistance for experimentation with improvements in urban mass transportation first became explicit in the Housing Act of 1961 and with the expansion of that program in the Urban Mass Transportation Act of 1964. Under this legislation and subsequent amendments, the Federal government continued its commitment and financial support for research and development of public transport improvements.

The transportation demonstrations that followed were primarily for rail and bus systems and covered a broad range of operational improvements designed to attract ridership. Experimentation was made with schedule changes, fare decreases and increases, fare collection methods, improved speed of headways, new equipment, and new systems or special services. In early stages of the demonstration program, a major effort was directed at improving commuter services for the journey-to-work. Congestion (most critical in the heavy traffic streams of peak hour work-oriented travel), not air pollution, was the impetus for this effort. As indicated in an IPA study of the first generation of these transportation demonstrations, some measure of modal diversion (i.e., motorists attracted away from their automobiles) was accomplished and a number of definite marketing lessons were learned. See Ralph E. Rechel and Lee H. Rogers, Review and Analysis of Reports of Mass Transportation Demonstration Projects (Washington, D. C.: Institute of Public Administration, 1967).

Bus Systems

Since streets and highways constitute the most pervasive transportation network in this country, and since rapid rail systems are available in relatively few U.S. cities, mass transit for most Americans means bus service. Of total passengers carried by transit services in the United States in 1970, almost 70 percent were carried by bus.[1]

Bus systems present a promising area for improvement because they can go anywhere on present rights-of-way. This ubiquity is important because buses afford the potential for door-to-door (or nearly so) service, and because buses can avoid the costly and time-consuming acquisition and construction of their own rights-of-way. The former is essential if significant patronage is to be attracted in the future; the latter is necessary if improvements are to involve relatively low initial investments and to be implemented in the short term.

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[1] American Transit Association, 1970-71 Transit Fact Book (Washington, D.C.: 1971), p. 3.

Scheduling usually stresses provision of bus for work trips, with express services provided in some cases. In most central cities, flat fares are used, and where suburban services exist a zone fare is provided. Equipment now in use in the United States is essentially homogeneous, the only real difference being whether air conditioning is used. Almost all bus services operate on roadways shared with automobiles; as a consequence, they are frequently caught in the same traffic jams.

Existing bus service may be enhanced by (1) exclusive bus lanes, (2) bus priority systems, and (3) a variety of operational and service improvements.

Exclusive bus lanes. One approach to alleviating bus delays would be to provide buses with their own reserved lanes, either physically separate from freeway traffic (e.g., the so-called busway) or on special "bus only" lanes on city streets.[1] Technologically, exclusive bus lanes are entirely feasible, although they have been infrequently tested. Approximately five exclusive bus lanes are presently in operation, and at least four are in the planning stages.[1]

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[1] Rights-of-way for exclusive bus lanes may be secured in a number of ways such as: construction of a new grade-separated roadway, including those in the medians of existing divided highways; dedication of bus only lanes in existing expressways or streets in the dominant traffic direction; dedication to buses only of lanes from the opposite direction of lightly used roadways during peak hours (i.e., by lane reversal). Conversion of existing railroad rights-of-way to bus use has been actively planned in Atlanta (since reversed) and Pittsburgh. This approach could obviously be used in Washington, D.C., and several other of the metropolitan areas considered for the study.

An obvious problem with exclusive bus lanes is the difficulty of fitting new rights-of-way into existing urban street and highway systems. Less evident is the paradox that establishing exclusive bus lanes may well increase congestion (and concomitant emissions) by increasing overall delays. Except in very few cities -- New York being one example -- buses do not run often enough to use up the roadway capacity assigned to them on an exclusive bus lane basis. Hence, from a transportation point of view, if one lane of a four lane highway is given over entirely to buses, the time saved by bus riders will never quite compensate for the time lost by motorists in the remaining three lanes.[2]

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1. Exclusive bus lanes exist for the Washington, D.C. area, where a busway of about 12 miles along I-95 in northern Virginia (the Shirley Highway) is the first such project which has been federally assisted; the New York City area where express bus lanes between New Jersey and Manhattan (the Lincoln Tunnel) have been operating since the late 1960's, and where a lane reserved for buses between Long Island and Manhattan (the Queens Midtown Tunnel) has been in operation since 1971; Seattle, where eight feeder routes of the "Blue Streak" express bus service all use an eight-mile segment of reversible lanes on the I-5 Seattle freeway; San Francisco, where the Oakland Bay Bridge has an exclusive lane for buses of the Alameda-Contra Costa transit district; and Boston, where an eight-mile exclusive bus lane on the southeast freeway (from Quincy to Boston) is presently operating on an experimental basis. Busways are planned for Los Angeles (between El Monte and L.A.); Pittsburgh (to feed into the CBD); Milwaukee (extending west from the CBD); and San Francisco (along U.S. route 101 in Marin County and across the Golden Gate Bridge).

2. See Highway Research Board, National Cooperative Highway Research Program Report 84, Analysis and Projection of Research on Traffic Surveillance, Communication, and Control (Washington, D. C.: National Academy of Sciences-National Academy of Engineering, 1970). One way out of this problem would be to allow some motorists (e.g., car poolers) on to the lane, but not enough to clog its capacity (at which point even minor perturbations in the traffic stream may cause slowdowns or stoppages). The idea has never been tested but is in the planning stage in several cities.

Bus Priority Systems. **Priority systems can improve bus flow on freeways (e.g., through use of exclusive bus ramps and lanes, and the metering of automobiles) and on city streets (e.g., with bus-activated traffic signals).**

Metering motor vehicles on to freeways involves controlling the flow at a rate which maintains traffic speeds at some defined level below the point of congestion.[1] Under a freeway system for buses, buses would not be "metered on" as would other vehicles, but would enter the freeway "at will," perhaps on their own bypass lanes as is now done in New York City at the Lincoln Tunnel. Priority access, of course, could be combined with priority lanes on freeways (see "Exclusive Bus Lanes" above).

Since most buses travel over city streets, street priority systems are especially significant. Most traffic control systems today are designed to move vehicles, without respect to differences in vehicle size and/or carrying capacity. Street priority systems for buses could be programmed to accord priority to people -- not vehicles -- so that the passenger carrying capacity of the street system would be improved. Operationally, these measures entail programming traffic lights so as to accord priority to loaded buses (e.g., by prolonging green signals for their utilization).[2]

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[1] Traffic flow techniques for city streets and urban arterials are discussed in Chapter 3 and Appendix D.

[2] Sensing the approach of buses in traffic may be done in several ways. One system already on the market uses a rapidly pulsing optical beam to transmit signals from an approaching bus to an electric phase selector which controls the traffic light.

Extensive use of street priority systems can have important effects in reducing bus delays. For example, a study conducted in Delft, Netherlands, calculated that the effect of influencing a series of ten traffic lights could reduce bus delay times from 191 seconds to 37 seconds.[1] In addition, schedule reliability could be substantially increased.

In general, the technology for street priority systems is relatively simple and the price tag for most large cities is probably in the range of about $2 million, a sum which represents an add-on cost to an existing program for traffic signals which would be required to move all vehicular traffic, including buses. (Under this approach all vehicles must move smoothly; otherwise the buses which are generally mixed in the traffic stream will be slowed down as well.) Street priority systems may also be usefully combined with express bus service and other bus improvements,[2] particularly for line-haul journey-to-work trips.

Operational and service improvements. Bus services in most cities could be greatly improved (and ridership increased) by any of the following operational or service improvements:

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[1] Organization for Economic Co-operation and Development, Consultative Group on Transportation Research, "Improvements and Innovations in Urban Bus Systems." Proceedings of the First Technology Assessment Review (Paris: OECD, October 1969).

[2] Automatic vehicle monitoring (AVM) could be used to improve bus services, either in combination with a street priority system, or independently. In and of itself, AVM information would enable better control of existing bus operations, adherence to schedules and greater economy in the use of buses. Aided by a computer, AVM information on loading conditions and passenger counts could hold out the promise of dynamic re-routing and rescheduling of buses to adjust routes and schedules to changes in demand or traffic conditions.

1. Additional express service, especially provision of express service for longer distances than presently available, perhaps with longer runs on freeways and expressways. Improved and more flexible design of pick-up and delivery routes could also help.

2. Increased frequency of schedules to help reduce door-to-door travel times. Deterioration of transit service in recent years has driven away many riders because of the long headways (i.e., the time between buses).

3. Reduction of fares, especially in base fares to 25¢ or less. However, this is only of moderate importance because demonstration projects have shown people will pay high fares, including an increase, for notable improvements in quality and convenience of service.

4. Improvements in schedule reliability. This could be developed through use of vehicle locator systems. Unreliability of service is a valid basis for rejecting much of the present transit system service.

5. Facilitation of inter-modal transfers through use of shelters, posting of connecting schedules and reliable schedule adherence. Multiple mode trips (or even multiple line trips) are at present disagreeably long, unreliable and exposed to the weather in most areas.

In addition to the above operational and service improvements, ridership might be increased over the long term by improving the quality of equipment. In the short term, new bus designs are probably not possible, but a reduction in the average vehicle fleet age to about five to seven years, and the universal use of air conditioning would help encourage bus use.[1]

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[1] In the medium term buses could be designed for fewer emissions and less noise, smoother acceleration, better ingress and egress, and either much easier steps to climb or none at all.

Taxi Systems

Taxis are a common sight on American streets, although the taxicab mode is seldom considered under the category of public transportation. Traditional taxi service differs from rail and bus systems in that (1) it does not provide a "mass" service (except for the occasional shared rides permitted in some cities); and (2) it operates with completely flexible routing (except perhaps for the occasional jitney service along fixed or semi-fixed routes). Because of its special characteristics, the taxicab has seldom been included in studies of public transportation.[1]

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[1] This omission can hardly be justified, however, in view of the fact that the taxicab mode accounts for a significant portion of all public transportation trips in some metropolitan areas. In the New York City region, for example, nearly 1 million person-trips are made in taxicabs on an average weekday, as compared to 4.5 person-trips made in the subway. See, Tri-State Transportation Commission, Who Rides Taxis? Regional Profile, Vol. I, 1969.

In Washington, D. C. approximately 99,000 person-trips are made in taxis on an average weekday, while bus service -- currently the only other public mode -- provides about 336,000 person-trips within the same period. From survey data as cited in Ho-Kwan Wong, "Some Demand Models for the Taxicab System in the Washington, D.C. Area," (unpublished working paper, Washington, D.C.: The Urban Institute, 1971).

In addition to traditional taxi operations, the taxicab mode may be said to encompass a variety of other taxi or taxi-like services, as summarized in Table 5-1.

Table 5-1

VARIETIES OF TAXI SERVICE

Service	Description	Experience
Jitney Service	Usually larger vehicle (12-15 passengers) than standard taxi, serving many origins to many destinations, on fixed or semi-fixed routes in center cities and adjacent to main transit routes or terminals. Shared ride. Usually not permitted by existing franchise systems.	Jitney service along Mission Street in San Francisco. Pittsburgh has an extra-legal system and there are undoubtedly others in the United States. In foreign countries, jitneys are quite evident and carry large proportions of total daily passengers in many cities.
Shared Taxi Service	Group riding. Occupied taxis may be flagged down on street. Many origins to many destinations service.	Required by legislation in Washington, D. C.
Taxi Car-Pooling	Pre-arranged car-pooling by taxi by suburban commuters to CBD.	Appears to be fairly widespread phenomenon in Washington, D. C.

Like buses, the taxicab mode is attractive for its ubiquity; it can go anywhere on the existing street system. Unlike buses, however, the taxicab mode can be used to service the lower density districts in many metropolitan areas where travel demand is so small and trip patterns so dispersed that it is not economically feasible to route and schedule transit buses. Taxis are suited to handle these low volumes of demand. Particularly if the taxi mode were developed into a demand-responsive system (see below) substantially more off-peak business could be attracted than is possible for conventional transit, thus reducing dependence on motor vehicles (particularly the second car). Improvements in the taxicab mode (short of the demand-responsive systems discussed below) can be made in two areas: (1) taxi dispatching and (2) existing taxi regulations.

Improvements in taxi dispatching. Today's dispatching for the taxi mode encounters three distinct but related problems. First, dispatching is hindered severely by driver recalcitrance (e.g., the refusal of drivers to indicate their whereabouts and availability). Second, even with better driver compliance, present-day dispatching would be time-consuming and inefficient.[1] Third, with today's methods, the coordination of large-scale taxi fleets is cumbersome.[1] Either individually or in combination, these problems tend to produce long delays in responding to telephone requests for service (and probably, less taxicab ridership as a result).

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[1] Typically, dispatchers spend much of their time searching for available vehicles in the vicinity of calls for service. For example, a dispatcher may begin by asking if an empty cab is at the nearest taxi stand. If not, he will ask if someone is cruising in the vicinity or is at a nearby stand. If he gets several responses, a discussion may be necessary to determine priority. If he gets none, he may suspend the search for several minutes, then try again. In rush periods it may be a long while before he tries again, even longer before he succeeds.

A computer-aided dispatching system[2] would open the possibility of dramatic improvements by enabling dispatchers to monitor large numbers of vehicles and assign each service call to the nearest available vehicle. The same system could also be used to assure driver adherence to planned policies (e.g., guaranteed pick-up and delivery and maximum waiting and travel time) and to check driver reports on the number and distance of trips served. Use of the computer could also improve taxi service by large fleets (management and regulatory policies permitting) by combining all taxis in a metropolitan area into a single fleet for dispatching purposes.

At the present time, computer-aided dispatching is still in the experimental stage. The pioneer in this field, Yellow Cab Company of Los Angeles, is currently field testing a computerized dispatch system for its fleet of approximately 700 vehicles. Depending upon the outcome of these tests, use of computerized dispatch may spread to other metropolitan areas, although the applicability of this system (as well as its cost and effectiveness) in other less spread-out areas may have to be demonstrated.

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[1] Using present methods, a good dispatcher can handle perhaps 150 requests per hour. However, it is difficult for several dispatchers sitting in a room to coordinate their efforts for large numbers of vehicles, although some crude techniques for doing so exist. Hence, the capability of each dispatcher limits the economies of scale which might be realized through dispatching.

[2] Such a system could be informed by automatic vehicle monitoring (AVM) data on the location and status of cabs, along with service requests and their time of arrival; or such information could be provided by conventional radio communication.

Revising taxi regulations. Regulations concerning taxi operations exist in all U.S. cities and have an important bearing on the quality and quantity of service offered.

A common regulation is to restrict entry into the market. Entry restrictions can be accomplished by placing a limitation on the actual number of cabs permitted to operate within a city (e.g., New York where the number of medallions is limited to almost 12,000); or by establishing a per capita cab ratio (e.g., Miami which specifies one cab per 1500 population); or by granting one or more exclusive franchises. Such franchises may be geographically exclusive (e.g., Los Angeles has six cab companies for six zones) or may be limited to one or two exclusive franchises for an entire city.[1] Another oft-encountered regulation is the officially set fare. The officially set fare is especially onerous[2] when it fails to allow rates to rise in rush hours when taxi costs can increase because of street congestion.

Both restraints have tended to keep taxi fares higher and utilization rates lower than they might otherwise be. In Washington, D.C. (with no serious entry restrictions) the fact that taxis are greater in number, more extensively used, and at lower fares, suggests what could result from less rigid regulations. (At peak hours, similar limitations on entry into specialized bus and jitney services may be quantitatively much more important.) Eliminating existing entry restrictions, however, would pose a number of institutional problems (see below "Institutional Feasibility").

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[1] General Research Corp., "Characteristics of Taxicab Supply and Demand in Selected Metropolitan Areas," internal memorandum (Santa Barbara, Calif.: General Research Corp., 1967).

[2] Onerous on the drivers to be sure, but also on the public, which finds cabs in operation at peak hours when they are most needed.

Demand-Responsive Systems

Demand-responsive systems have been developed under a variety of names including Dial-A-Bus,[1] Demand Actuated Road Transit (DART)[2] and others.[3] Perhaps the most descriptive designation is taxi-bus since the system combines some features of both a taxi (door-to-door service) and a bus (sharing rides and reduced fares).

Demand-responsive systems can be designed to operate with or without fixed schedules or routes, picking up passengers at or near their doors on a real-time (i.e., demand-responsive) basis and delivering them within proximity of their destinations. With riders sharing the vehicle, fares might be reduced by as much as one-half from existing levels, thereby tapping a substantial new market.

At the present time, some small-scale manually dispatched demand-responsive services are appearing in inner cities, where low income residents, many without automobiles[4] are entirely dependent upon existing transit (mostly bus) for mobility. In these areas, demand-responsive systems using vans are increasingly being used to transport the elderly, the handicapped, and job trainees to destinations they cannot easily achieve through traditional transit services. Usually, these operations involve scheduling by a dispatcher who receives requests for transportation at least a day in advance.

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[1] See, for example, Massachusetts Institute of Technology, "Dial-A-Bus" (paper presented by Alan Altshuler and Daniel Roos at the Fifth Meeting, Consultative Group on Transportation Research, Organization for Economic Co-Operation and Development, Directorate of the Environment, Paris, October 1970).

[2] Institute of Public Administration and Teknekron, Inc., Demand-Actuated Road Transit (DART), Performance and Demand Estimation Analysis. Report to the U.S. Department of Transportation (Washington, D.C.: Institute of Public Administration and Teknekron, Inc., March 15, 1969).

[3] Demand-responsive systems may operate with or without computerized dispatch, although it is usually assumed that for large-scale fleets a computer, complete with scheduling algorithm and probably an automatic vehicle monitoring system would be required.

[4] As of 1970, 50 percent of all family units with an annual income below $3,000 did not own an automobile. Automobile Manufacturers Association, 1971 Automobile Facts and Figures (Detroit, Mich.: Automobile Manufacturers Association, 1971).

By approximating the comfort and convenience of an automobile (at fares significantly less than for taxis), demand-responsive systems are probably the only public transportation mode potentially capable of competing successfully with the private automobile.[1] However, absent a large-scale demonstration of demand-responsive systems (see below "Institutional Feasibility"), little more can be said about the kind of service which would be required to attract substantial ridership.

Car Pools

Car pooling may be defined as the shared use of private passenger cars, especially for the journey-to-work.[2] Encouragement of car pooling may take the form of tax relief or rebates, eligibility to use otherwise restricted lanes (e.g., busways) preferences or reduced prices for parking

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1. This would appear particularly true for the unstructured travel patterns (i.e., dispersed origins and destinations) characteristic of low-density cities such as Los Angeles and Denver.

2. Car pooling is considered in connection with the journey-to-work because (1) only work trips are sufficiently regular (in terms of departure and arrival times and origin and destination patterns) to permit pooling, and (2) because work trips tend to have average occupancy rates well below trips for other purposes, and hence offer the greatest potential for sharing of vehicles.

and/or bridge and tunnel tolls and improved information (e.g., a computerized car pool information service to facilitate formation of car pools).[1]

Aside from such "official" encouragement, there may be other existing incentives and disincentives to form car pools. For example, car ownership, operating, toll and parking costs can be cut substantially with car pooling to the point that, short of walking, no other mode of transportation is cost competitive.

Conceptually, car pools appear to have enormous potential for alleviating traffic congestion (and concomitant motor vehicle emissions) at peak hours. Average vehicle occupancy rates vary somewhat from city to city, depending as well on trip purpose, time of day, and place of use. But generally, these figures appear to be about 1.5 (driver plus an average of 0.5 riders) for the downtown areas of most American cities at peak hours.[2] Assuming other things equal, simple arithmetic shows that by increasing this figure to 2.0, a 25 percent reduction in traffic could be achieved.[3]

At the same time, however, the almost uniformly low occupancy rates for most U.S. metropolitan areas attest to the fact that car pooling in large numbers is seldom found. The reason is simply that car pooling is highly restrictive in terms of service offering;

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[1] These incentives, of course, could be combined with measures (such as the motor vehicle restraints discussed in Chapter 6) specifically designed to discourage use of motor vehicles with low occupancy rates. For present purposes, however, we confine the discussion of car pools in and of themselves without reference to motor vehicle restraints.

[2] At the low end of the range is Los Angeles with a 1.06 average vehicle occupancy for the journey-to-work. Source: Los Angeles Transportation Study, Origin and Destination Survey, 1967.

[3] Other things are not equal, however, as explained below, "Air Pollution Control Potential."

> Generally, car poolers are heavily constrained with respect to both the times and destinations served by the car pool. Car poolers need to work and live in close proximity, and to have common working hours. In a certain sense, the level of service afforded by car pooling is poorer for most than that available for transit, unless, of course, poolers can find similarly minded travelers with common work hours, home and work locations.[1]

In addition, of course, there is the common problem of many car pools -- the member who happens to be late either morning or evening or both.

Given these constraints, the feasibility of car pooling can be expected to vary from city to city, depending upon the degree to which employment centers are concentrated, work hours are standardized, and communication is facilitated among employees within and among different firms.[2]

Except where employment is concentrated in a small number of government agencies or firms, communication among potential car poolers is almost non-existent, and hence car pools are difficult to form. For this very reason, a number of new organizations are now promoting computerized information systems as one means of stimulating car pool formation.[1]

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[1] Martin Wohl, "Must Something Be Done About Traffic Congestion," Traffic Quarterly, XXV (July 1971), p. 408.

[2] As one transportation analyst has pointed out,

> Washington, D.C. especially lends itself to car pooling since more than one-third of Washington's downtown employment is concentrated in Federal agencies. Agencies often house hundreds, sometimes thousands, of employees who have a common destination and standardized working hours. Also...the Federal agencies frequently encourage car pooling unofficially with bulletin boards, route descriptions or a central point of inquiry.

Ibid., pp. 408-409.

Use of a computer would be beneficial in two respects: (1) by accumulating a massive data bank of all potential car poolers (regardless of location and work schedule considerations), and (2) by facilitating a matching of feasible car poolers. In a typical computerized system, employees might be given a questionnaire to which they would specify their home and work locations and schedule requirements. The computer would then search the data bank for feasible car pool formations.[2]

The extent to which an efficient information system could encourage car pooling cannot be resolved at this time, absent any large scale tests of computerized car pool systems. However, one small study by the State of California Department of Public Works was conducted for the San Francisco area, and does suggest the potential of these systems.[1] Although it cannot be considered conclusive, the study tends to confirm the view that such computerized systems alone would be of limited value.

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[1] "Operation Oxygen," a California group whose main purpose is to reduce smog by curbing the number of vehicles on the road, has succeeded in encouraging car pools in Pasadena (where 500 employees of the Burroughs Corporation are sharing rides) and at the State College campus in San Bernardino (where 400 of the 2,000 students and teachers formed car pools). In both cases, computers were used to identify people who lived in the same area but did not know one another.

[2] Particularly if car pooling on any significant scale is envisioned, a computerized information system capable of matching large numbers of shifting job and residential locations would appear required. Such a system by itself would probably not suffice to stimulate car pool formation on a large scale, but would be necessary if substantial car pooling were encouraged by other means.

In conclusion, riders who are not reasonably close neighbors at home and at work cannot be expected to share cars. And even where common travel routes make car pooling feasible, more tangible incentives than the desire to reduce congestion and pollution are likely to be necessary to stimulate commuters to travel together.[2] Car pools may be encouraged, however, by various measures involving selective application of motor vehicle restraints (see Chapter 6).[3]

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[1] In March 1970, approximately 12,000 postage free cards were distributed to commuters passing through the San Francisco Bay Bridge toll plaza. A questionnaire contained on the card solicited interest in car pooling and requested pertinent information for car pool matching. Slightly more than 10 percent (1,250) responded to indicate their interest in car pooling. The information was then key punched on computer cards and lists were compiled which matched resident and work area zip codes. Approximately one month later, a total of 1,050 lists were formed, reproduced and distributed. A return post card was then mailed with each list to the original respondents who were asked to advise the Department of any success in their attempts to form car pools. The result: 125 commuters responded, of whom only 32 indicated they had formed car pools, less than one-half of 1 percent of the group studied. Information from California Department of Public Works, Division of Bay Toll Crossings.

[2] The failure of a campaign to promote voluntary car pools in Los Angeles in October 1971 helped to make this point. Despite considerable publicity and efforts by more than 100 companies to organize computerized car pools, the effort failed, probably because of the highly dispersed patterns of origins and destinations of the commuters in the Los Angeles area.

[3] For example, where toll bridges or tunnels exist, fully occupied vehicles may be given a faster or cheaper passage in peak hours. Such a scheme was introduced on the San Francisco-Oakland Bay Bridge in December 1971. Cars carrying three or more passengers between 6 a.m. and 9 a.m. are offered a toll-free crossing and a 10-minute gain in time through not having to queue for tickets. The aim of the experiment, as yet not attained, is to increase the number of cars crossing the bridge with three or more people on board from about 2,000 to about 3,000.

People Movers

People movers may be defined as grade-separated systems of small dimensions, operating at moderate to low speeds with continuing access to the service at frequently spaced stations.[1] Capacities will probably range from 2,000 to over 10,000 riders in the peak-hour, depending upon the particular people-mover technology. At the present time there is a wide variation in the hardware and propulsion systems of people movers, although all are electric and pose little, if any, problem for the immediate environment. Virtually all people-mover systems, however, involve new and relatively untried technology; over the short-term, therefore, they will be available only in relatively small numbers through demonstrations or "first of a kind" installations.

The principal role of people movers is to move large volumes of people to and from transportation facilities, and to provide distribution routes in and around central business districts and other major activity centers. For example, they could be of major importance in moving motorists from park'n ride facilities to and from other activity centers in the central business district and in providing for some separation of pedestrian and vehicle traffic, thereby affording more orderly and (hopefully) more rapid vehicular flows.

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1. A large number of people mover concepts have been proposed and several are currently in use. A typical system would consist of small (i.e., one or two passenger capacity with room for parcels) automatically controlled capsules. Passengers using the system would enter the capsule at one of many sidings and push a start button. The capsule would be automatically accelerated and merged into mainline traffic; deceleration would be done automatically when the capsule is turned into a riding.

Air Pollution Control Potential

Promising as the above improvements may seem individually, they should not be allowed to obscure the larger reality. Extensive review of all recent evidence[1] leads us to conclude that public transport improvements alone hold little promise for major modal diversions. There are no prospects at all for attracting motorists to public transport by minor improvements. Only an all-out marketing effort, complete with variable scheduling and great increases in express services, can even hold present levels of public transport ridership. Moreover, modal diversion to public transport does not necessarily reduce motor vehicle traffic.[2] To have any appreciable effect on emissions, public transport improvements must be combined with motor vehicle restraints (see Chapter 6 and the analysis of the Philadelphia-Lindenwold line in Appendix E).

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[1] The few public transport success stories of recent years (e.g., the National City Lines in Rochester, New York, and the Reston, Virginia, Charter Services) have been carefully marketed efforts that meet specific consumer requirements and operate nearly door to door at nearly private passenger car speeds. People have demonstrated their willingness to pay higher fares for these services.

[2] For one thing, modal diversion may consist of riders attracted from one form of public transport to another (e.g., from bus to subway). When new rapid rail systems were developed in Chicago and Toronto, diversion occurred from the old bus or street car transit to the new systems with little new or added ridership generated. See Martin Wohl, The Urban Transportation Problem; A Brief Analysis of Our Objectives and the Prospects for Current Proposals (Washington, D.C.: Urban Institute, March 1970), p. 13.

Another possibility is that public transport improvements cause car pools to decrease in size as poolers shift into drive-alone situations to take advantage of increased highway capacity. Similarly, if traffic conditions improve to the point where substantial and obvious time savings are possible, other motorists may modify their journey to work patterns to take advantage of the new capacity. Or the additional capacity may be "soaked up" by trips attracted away from other corridors in the area.

Our major conclusion, therefore, is that improvements in public transportation are a necessary but not sufficient condition for reducing motor vehicle traffic (and hence, emissions). Improvements are necessary because restraining or restricting motor vehicle traffic in high pollution areas of central cities will require substantially better public transport service to provide an alternate means of trip making.[1] Improvements are not sufficient, however, since in the absence of accompanying motor vehicle restraints public transport improvements will reduce motor vehicle traffic only modestly, if at all. Indeed, emissions may actually increase where they are currently worst (i.e., in the downtown and other densely developed areas).

Historically, the effect of good transit has been to encourage the economic development of the CBD it serves. When a new transit system is installed, development tends to take place around the downtown stations of that line.[2] Development is especially intense at the node points -- where two or more lines cross. Since ground rents are high -- due in no small part to the new transit systems -- the new office buildings also tend to be high. As a result, more people tend to work in the downtown than was previously possible. Although a large number of new workers probably take the new, convenient transit system to work, some percentage will take their motor vehicles.[1] The proportion of new motorists may be small relative to transit users, but their absolute numbers are important, particularly at peak hours.

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[1] In no U.S. metropolitan area is there at present a rapid rail or bus system capable of satisfying all trip-making needs, even in the CBD. With a few exceptions, the proportion of people riding transit (entering the CBD on a typical weekday) tends to be less than 60 percent in most large cities. For attracting the remainder expansion of existing taxi service and the introduction of demand-responsive systems (e.g., taxi-bus) appear to be the best alternative.

[2] One can already see the high new buildings going up in San Francisco and more high rise construction has been recently approved. In Washington, the pressure is already on to lift building height limitations because they are "inconsistent with the new subway system." Those concerned with traffic congestion and air pollution may well watch these two cities during the next decade to determine the effects of subway developments.

Maximum Feasible Emission Reduction

Generalizations about public transport are always hazardous, since the industry serves patrons with diverse needs and in varied circumstances. Caution is particularly valid when projecting the extent to which motor vehicle emissions could be reduced from potential improvements in future service. It is clear, however, that public transport improvements alone hold out little promise for major modal diversions, much less a reduction in motor vehicle emissions. Our best judgment is that even extensive improvements (including some construction and renewal of equipment) would be unlikely to reduce vehicle miles traveled[2] (and hence emissions) by more than 5 percent in any major metropolitan area.

To determine the reasonableness of this judgment, a special analysis was conducted of traffic data along the corridor served by the Philadelphia-Lindenwold line. For a number of reasons, the Lindenwold Rapid Transit Line probably represents the best commuter rail service this country has to offer. Accordingly, it provides a good indication of the maximum feasible emission reductions which would be possible from public transport improvements.

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[1] They will be able to park in the basement spaces that new buildings usually have. Typically, new buildings built on a parking lot tend to have more parking spaces than the original area.

[2] Reference is particularly to vehicle miles traveled by light-duty motor vehicles (e.g., the private passenger car).

In Appendix E to this report, we describe how the Lindenwold line has combined speed, convenience and comfort at a moderate cost with an aggressively marketed transit service aimed at meeting the competition of the automobile. We conclude, however, that although the line has obviously made its mark on improving suburban rapid rail service, its impact on reducing motor vehicle traffic (and concomitant emissions) is less evident and more difficult to measure. A reduction in motor vehicle traffic directly attributable to the Lindenwold line has not occurred, at least as reflected in available data.

Institutional Feasibility

The problems of planning, organizing and financing public transportation improvements are pervasive and complex, exceedingly difficult to resolve and have received substantial attention in the voluminous literature on urban transportation.[1] Provision of public transport has probably been subject to regionalization more consistently than any other urban service. It is also more frequently provided by public enterprises and special authorities than by general government departments. On the whole, however, the administration of public transportation is also often the most functionally fragmented of urban services. Single purpose agencies (the Toll Road Authority, Parking Authority, Transit Authority or Airport Authority) abound, along with state and local government departments of highways and traffic. In many metropolitan areas, the search for administrative solutions to transportation is also complicated by a number of legal factors (e.g., governing eminent domain and land acquisition) as well as (in many cases) anachronistic public regulation of transit and taxi services. All the patterns are too complex for complete description here, and in the following we only attempt, therefore, to sketch the most salient issues.

Current Position of Public Transport

Although a number of institutional problems may impede, the major obstacle to implementing public transport improvements is simply lack of money. Appreciation of this problem requires recognition of the declining financial position of public transport systems across the country. In the past two decades, the transit industry has experienced a shrinking market as the highway construction program advanced and as automobile ownership increased. In 1950, U.S. transit lines carried a total of 13.8 billion revenue passengers. By 1970, that total had diminished to 5.9 billion passengers -- a decrease of over 57 percent.[1] Furthermore, the highway program -- in combination with other factors -- has encouraged low-density land-use patterns with their dispersed origins and destinations. Most of the transit industry has not been able to profitably service low-density dispersed travel, and nationally most public transportation systems have been operating with a deficit since 1963.[2]

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[1] For some of the more important works, see bibliography attached to this report.

There is no available evidence that this long-term decline in ridership (which has continued without deceleration in the past decade), will either cease or noticeably slow down. This means that in another eight to ten years the smaller metropolitan areas will have only 10 to 15 percent of the public transportation ridership they demonstrated in

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[1] American Transit Association, 1970-71 Transit Fact Book, Table 5 (Washington, D. C., 1971), p. 6. The 1970 total is a preliminary figure.

[2] *Ibid.*, Table 1, p. 4. Transit problems have been compounded in recent years by inflation, lack of capital to replace aging equipment and rising labor costs. In the latter connection, it is important to understand that mass transit is a highly labor-intensive business -- about 65 percent of transit operating costs are associated with labor.

1950; while metropolitan areas between 500,000 and 2,000,000 will have 60 to 75 percent of their 1950 ridership.[1]

It must also be concluded from all available evidence that traditional, rigidly routed, scheduled transit service does not meet the needs of a vast majority of people in metropolitan areas under 2 million people. And even in the larger metropolitan areas, rail (and particularly bus systems) have been undergoing fierce competition with motor vehicles since at least the end of World War II. At the present time, in terms of comfort and convenience (and, for some trip purposes, cost) the personal passenger car is unequaled by any public transport technology now in use.

Within this context of deficits, failing operations, poor equipment and declining service, and given the attractions of the private passenger car in terms of privacy, convenience, freedom of movement and the like, the reasons for the difficulty of enticing Americans out of their automobiles become clear.[2] It is equally apparent that if public transport is to compete effectively, its services must be significantly improved.

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[1] Institute of Public Administration, "The Present Condition and Characteristics of the Transit Industry and How they Evolved," draft report, Washington, D. C., September 1971. (Mimeographed.)

[2] It has been seriously estimated that public transit riders would have to be paid 50¢ or more per trip to induce a majority of motor vehicle commuters to give up their private passenger car in Chicago's circumstances. (See Leon N. Moses and Harold F. Williamson, Jr., "Value of Time, Choice of Mode, and the Subsidy Issue in Urban Transportation," Journal of Political Economy, LXXI (June 1963), pp. 247-264. More recently, a Gallup poll indicated that 81 percent of U.S. citizens use the automobile for the journey to work. This percentage, which is, of course, even higher for other trip purposes, has been confirmed by surveys taken by the Bureau of Census. A recent census survey indicated that 82 percent of workers traveling more than one-fourth of a mile from home use the automobile to commute to work. See U.S. Department of Commerce, Bureau of the Census, Home to Work Travel Survey, cited in Automobile Manufacturers Association, 1971 Automobile Facts and Figures (Detroit, Mich.: Automobile Manufacturers Association, 1971).

Rapid Rail Systems

Construction of new systems. As indicated earlier, only the rail systems for San Francisco (BART) and Washington, D.C. (Metro), (of the cities examined in this study) could potentially be opened for service in the short term (by 1977). Both systems could be expedited somewhat by additional (mainly federal) funds, since in both cases the politically difficult and time-consuming task of acquiring rights-of-way and road bed facilities has been accomplished. Additional funding, however, is by no means clearly in view, either from the Urban Mass Transportation Administration's Capital Grant program (see below) or from local matching funds. Even with more funds, accelerated construction would probably be constrained by the limited supply of experienced contractor and supervision capabilities.

Most public transport systems depend upon government subsidies to cover part of their operating expenses, and are totally incapable of financing the complete cost of capital improvements from user revenues. As a result, if the improvements in public transportation are to be made, funds for such purposes must be derived primarily from loans and grants at one or more levels of government and/or borrowing on agency credit, usually with government approval. (The exception, of course, concerns highway programs which are financed largely from earmarked gasoline taxes.)

The Urban Mass Transportation Assistance Act of 1970 (84 Stat. 962) commits the Federal Government to obligate $10 billion by 1982 for capital grants to improve transit systems. It authorizes $3.1 billion in contract obligations over the first five years of the program. However, as of early 1972, this $3.1 billion fund for capital improvements was already entirely allocated.

These federal funds (i.e., the $10 billion obligated for capital improvements) may be compared with our estimates of the capital requirements for public transport improvements in the six cities under study (see Introduction and Summary of this report, "Preliminary Cost Estimates for Public Transport Improvements"). Our estimates indicate that about $13.8 billion would be required in terms of capital investment if existing plans plus some moderate improvements (such as people movers) are implemented in the cities of New York, Chicago, Washington, D.C., Los Angeles and Denver. These estimates must be considered conservative since they do not include the scope of changes (i.e., substantial improvements) which apparently would be needed to meet national air quality standards by 1975.

If (as is provided for under the 1970 Urban Mass Transportation Assistance Act) the Federal Government were to contribute two-thirds of these capital investment costs, over 90 percent of the total $10 billion available for the entire country would be expended for just the six cities under study. If more and better public transport is to be made available, a significantly greater federal commitment would clearly be required.[1]

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1. Department of Transportation Secretary John A. Volpe recently requested Congress to allow part of the federal money now earmarked for highways to be used for public transportation. The money would be taken from the Highway Trust Fund, a special part of the federal budget that is financed by highway user taxes and now can be spent solely for highways. Under Mr. Volpe's proposal $1.5 million from the Fund would be made available to urban areas for public transport in the fiscal year beginning July 1, 1973. The amount would rise to $1.85 billion in the next fiscal year and to $2.25 billion after that.

The proposal, however, appears certain to face substantial opposition in Congress (especially among some members holding key committee positions), and were it to be enacted the approval of six Congressional committees would probably be required.

Extensions of existing systems. As in the case of constructing new systems, the most important institutional problem in extending new rapid transit lines is additional funding, funding which does not appear available at the present time.

Operational and service improvements. The operational and service improvements identified earlier for rapid rail systems include: (1) reducing fares, (2) increasing comfort, cleanliness and safety, (3) increasing schedule frequency, (4) providing park 'n ride, and (5) improving fare collection. Since extensive and continuing subsidies would still be required, even after paying for such improvements, the major institutional problem is simply that at present there is no source of operating subsidies, except from state and local taxes. The problem of obtaining funds to cover large operating deficits of transit operation applies equally to rail and bus systems. In most cases, only the Federal Government appears capable of covering these operating deficits, let alone of funding major operational improvements.[1] Without extensive federal assistance, improvements in public transportation for most metropolitan areas are unlikely to be made because of fragmented state and local jurisdictions, various organizational and managerial deficiencies, and inadequate available financial resources. For all practical purposes, no federal funds are available at the present time to subsidize operating deficits, let alone to finance major improvements.[1] There appears to be some support in Congress for such subsidies,[2] and Administration proposals have been presented. Therefore, the feasibility of federal funding for transit operations and improvements will depend in large measure on the outcome of the ensuing political process.

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[1] Particularly during the last decade, state and local subsidies for public transportation have increased substantially. Important examples include New Jersey, where the State, through its Department of Transportation, administers aid programs for commuter rail and bus transit services; Pennsylvania, where the Commonwealth has continuing a program of operating assistance for mass transit, coupled with a state program for capital grants which works in tandem with the Federal Capital Grants program; and New York City, where public transportation in the New York City region is provided by the Metropolitan Transit Authority (MTA), the Port of New York Authority Trans-Hudson Corporation (PATH), and seven privately-owned bus companies operated in Manhattan and Queens. A number of other states and localities have also been moving to support public transportation. Last year, for example, the California Assembly approved a bill to extend the state sales tax on gasoline to raise approximately $129 million annually to subsidize public transportation.

Probably the most dramatic program of local support for public transport in recent years was the approval by Atlanta voters in November 1971 of a new regional sales tax that will not only underwrite much of the construction costs for a new rapid rail system, but will also subsidize fares (the current fare on buses, 40¢, will be cut back to 15¢ soon because of the new tax).

In addition to availability of funds, a federal subsidy to transit operators would pose a number of administrative problems including: (1) service units (e.g., passenger miles traveled) are difficult to define, measure and audit; (2) unless the conditions for federal subsidies are spelled out very specifically, money may be dissipated by labor demands and wasteful management practices; and (3) it is far from clear who would

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1. Some federal funds are available through a few demonstration projects, but these are largely limited at present to poverty areas not well served by motor vehicles. Hence, the potential for reducing motor vehicle use through public tranportation in these areas is exceedingly small.

2. Several attempts have been made recently to pass legislation to provide subsidies for operating deficits of mass transit systems. A typical bill would provide grants of up to 50 percent of any mass transit operating deficit over a period not to exceed three years. As of early 1972, an approach actively under consideration in Congress would provide operating subsidies to mass transit systems by authorizing a simple, two-paragraph addition to Section (8) of the Mass Transportation Act. The amendment would expand the $10 million program of capital grants to transit systems and would be included as a small part of the Housing and Urban Development Act of 1972, a measure more than 500 pages long. Funds for the subsidies would come from the $500 million in transit funds now impounded by the Administration and from a multibillion dollar increase in the program's long-term contract authority which, by law, must be extended in 1972.

be the appropriate administering agency (e.g., a federal department, state or local governments, an area-wide transportation authority).

Bus Systems

Most of the improvements identified earlier for improving bus service require little or no capital investment. Extensive and continuing operating subsidies, however, would be required, and, to this extent, the unavailability of these funds (other than from federally funded projects[1] or state and local taxes) constitutes the principal institutional problem.

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[1] In addition to the Urban Mass Transportation Administration's demonstration program (as already mentioned), another federal program should be noted. The "Urban Corridor Demonstration Program" is an attempt to combine Highway and Urban Transit projects in a package approach to deal with severe instances of urban traffic congestion. The program was initiated in January 1970 by the U.S. Department of Transportation with the stated purpose of drawing upon various transportation program resources to focus on specific congested corridors. Possible funding sources include UMTA grants for facilities, equipment, and research studies as well as Federal Highway Administration grants for TOPICS and related construction projects. (Some limited funding was also made available for this specific program.) General guidelines were stated to delineate the type of congested corridors the program was to affect (e.g., peak hour travel speeds of 20 mph or less and traffic volume-to-capacity ratio approaching one during the peak hour).

In outlining the program, DOT suggested a number of improvements which could be considered by cities in applying for funding. These included fringe parking near transit facilities, demand-activated collection systems, traffic restraints, exclusive bus lanes, signalization schemes to favor buses, and transit fare and parking price experiments. A prospective city could propose any combination of such efforts to be applied to a particular corridor.

Secretary of Transportation Volpe announced on July 1, 1970, contracts totalling almost $2 million to be awarded to eleven cities for preliminary planning of their projects. Preferential access to streets and freeways for transit and exclusive bus lanes were the predominant strategies, proposed in some form by eight of the cities. Other proposals accepted included a system of satellite terminals with parking and heated bus shelters (Cincinnati), collection-distribution systems utilizing feeder buses and improved parking facilities (Philadelphia) and a new bus terminal design and operation system (Washington, D. C.).

Some capital investment would be required for one of the most promising improvements in bus services (i.e., the operation over exclusive or preferential lanes of more buses on non-stop express schedules between line-haul entry points and downtown areas). Modest outlays would be required in the event that these services require modification of existing roadway facilities, or special grade-separated rights-of-way (perhaps by taking over abandoned or under-utilized railroad beds).

Use of existing highways or streets for express bus lanes may be obtained in a matter of months, as has been demonstrated in several recent experiments, two of them in New York City (the Lincoln Tunnel approach and the Long Island expressway to Queens-Midtown Tunnel approach).[1]

In the Queens-Midtown Tunnel case, the estimated annual cost of the venture is $150,000. The cost is presently being borne by the New York City Department of Traffic in using its own personnel and equipment, although, Traffic Commissioner Theodore Karagheuzoff has said that he hopes the plan will be financed by the Federal Government eventually.

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[1] In the latter case, a special lane was set aside for express buses on the congested Long Island expressway. The new lane is along the last two miles of the expressway before it enters the Queens-Midtown Tunnel and was made by reversing the direction of one of the three eastbound lanes. The lane is in use for buses from 7:00 a.m. to 10:00 a.m. on weekdays, after which it is turned back to an eastbound lane.

Recent reports indicate that the express buses running along this route are at 80 percent capacity and carrying about 6,500 people for an average of about three and a half minutes on the two miles to the tunnel. Motor vehicles traveling the same distance in the three westbound passenger lanes have been averaging about eighteen minutes. A similar reversing of one lane during rush hours has been in effect in New Jersey since December on the approach to the Lincoln Tunnel.

For all but the largest cities federal funds appear necessary for the implementation of exclusive bus lane improvements.[1] Some improved busways may be financed with funds from the Federal Highway Administration, but these funds would have to be taken from the regular construction programs, which are hard fought after and closely watched by highway interest groups.[2] The Urban Mass Transportation Administration is taking some steps towards financing busways, but there still have not been a great many applications. Until more interest is expressed and pressure brought to bear, the UMTA will probably not expand this program.

Aside from lack of subsidy funds (and agreement upon ways of administering these) additional institutional problems in implementing improvements are: (1) the functional fragmentation of agencies providing transportation services, (2) the historic hostility in many areas between local governments and transit operators (e.g., in Washington, D.C., between Washington Metropolitan Area Transit Authority, the District Government and D.C. Transit System, Inc.) over matters of money and management, and (3) the poor marketing efforts mounted by most transit operators.

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[1] As noted elsewhere, however, these capital investment requirements are relatively modest when compared to most rapid rail improvement programs. See Introduction and Summary of this report "Preliminary Cost Estimates for Public Transport Improvements."

[2] In addition, some local departments of highways and traffic (particularly in medium- and small-sized cities) may not be presently prepared to propose and/or sponsor bus system improvements. Traffic engineers in these departments may be opposed to disrupting their way of doing things, preferring instead to rid their streets and highways of "dirty, noisy and smokey buses" to make room for private passenger cars. As indicated, these attitudes, of course, are by no means uniform. In some of the larger cities local departments of highway and traffic have taken the lead in facilitating express bus service over exclusive busway or preferential lanes.

In the latter connection, the transit industry may be characterized as less confident and more resistant to change than most. For decades, transit operators have been oriented towards servicing a steadily diminishing captive ridership under conditions of public regulation which leave little room for initiative. Declining ridership, technological stagnation[1] and rapidly rising labor costs have led to the approval of higher fares (under the assumption that operations should be paid for "out of the fare box"). Ironically, service has increasingly been for those least able to pay. However, even the fare increases, coupled with service cutbacks, have failed to keep most transit systems out of the red. As a result the industry has been unable for the most part to attract dynamic young managers. Some well managed systems can be found, but they are far from the norm.

Taxi and Demand-Responsive Systems

The extension of taxi services to reach their full or even reasonable potential would entail substantial institutional changes (with respect to licensing, franchising, rate making and so forth). Among the most pressing changes which could be considered are the establishment of free entry for taxis (found at present among the metropolitan areas we are examining only in Washington, D. C.), the use of differential peak and off-peak rates and the use of computer-aided routing and dispatch.

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[1] Substitution of buses for streetcars has been the only real technological change in transit during the past century.

The major institutional problem concerning demand-response systems is simply the lack of a computer-aided demonstration.[1] The Urban Mass Transportation Administration is currently sponsoring two demand-responsive demonstration systems, although neither is computer-assisted.[2] Studies of the potential market, however, have concluded that in order to assure a sufficient demand for these systems, computer-aided routing and dispatch should be an essential part of the service. In the judgment of these researchers, work on demand-responsive systems has progressed to the point where a demonstration of a computer-aided system is desirable now.

> Numerous local communities have expressed a strong desire to play host to such a demonstration. The purchase of equipment, hiring and training of drivers, etc., would require a lead time of about six months from the day of the decision to fund the initiation of service, but technology is ready.
>
> At the six month point from decision day, it would be possible to have ten vehicles in operation. In twelve months, twenty-five vehicles could be in operation. In eighteen months, the number could be fifty or more. Further development of the computer programs will be required to support larger systems. Within a decade, however, there is no reason why systems involving thousands of vehicles should not be technically feasible and cost-effective where large metropolitan markets justify them.[3]

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[1] Demonstration is required to determine the public acceptance and use of the service, profitable operating costs, the most appropriate collection and distribution, and so forth.

[2] In the first demonstration, twelve small vehicles of up to 15 passenger capacity will carry commuters to the Haddonfield, N.J. station of the new Philadelphia-Lindenwold line. Initially vehicles will be manually dispatched from many origins to one destination, although a scheduling algorithm is to be developed for later application.

[3] Massachusetts Institute of Technology, "Dial-A-Bus" (paper presented by Alan Altshuler and Daniel Roos at the Fifth Meeting, Consultative Group on Transportation Research, Organization for Economic Co-operation and Development, Directorate of the Environment, Paris, October 1970), p. 99.

Federal funding for a computer-aided demand-responsive demonstration, however, appears unlikely until the present limited experiments have operated long enough to make preliminary judgments.

The implementation of demand-responsive systems will probably face serious institutional problems, largely legal in nature, but which also relate to the usual resistance to change by parties who presently have exclusive franchises to provide transportation services. From the standpoint of regulatory law, demand-responsive systems would combine characteristics of both the taxicab and the bus. Generally speaking, if these systems are established as private bus companies and must meet existing regulations and laws pertaining to bus franchises, difficult procedural problems will have to be solved. If demand-responsive systems are established as taxicab service, fewer problems of regulatory law exist -- at least for most jurisdictions. On balance, in many jurisdictions some statutory, even constitutional, relief may be required before extensive operations of a demand-responsive system may be implemented.

Car Pools

There do not appear to be significant institutional or technical problems with car pooling schemes, and they could be made available in a relatively short period of time. As indicated earlier, however, short of very powerful incentives, there is little ground for believing that car pools alone could be effective in reducing motor vehicle emissions. Tangible incentives would probably require some public funds, and in the event of use of restricted lanes, some additional encorcement costs may be imposed.

People Movers

The institutional problems in implementing people movers could be important. Several years will probably be required to solve problems expected to emerge among designers, environmentalists, and building owners over what is the most appropriate manner in which to install people mover systems. There may have to be some use of public acquisition powers, and unquestionably a considerable amount of air and other right compensation to property owners. Although people movers could be put underground, costs would probably double from the currently estimated $2 million to $3 million per mile (fully installed). Consequently, tunneling represents a relatively costly solution. Most people mover systems would have to be "public" and substantial amounts of money would have to be raised. Again, federal financing would probably be required.

CHAPTER 6

MOTOR VEHICLE RESTRAINTS

Definition of Terms

In the present chapter we consider various measures which could reduce to some degree motor vehicle use[1] in high air pollution areas. These measures, termed motor vehicle restraints, consist of controls over parking and/or road use, whether by administrative action or pricing policy, as summarized in Table 6-1. Subsequent sections discuss the air pollution control potential of these motor vehicle restraints and their institutional feasibility.[2]

Regulating Parking

The location, amount and use of parking can be controlled by administrative action (i.e., without public intervention in pricing).[3] In most metropolitan areas there are three categories of vehicle storage capacity

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[1] The motor vehicles to be restricted or restrained could consist of private passenger cars, transit vehicles, taxis, trucks or some combination thereof.

[2] In our view, the following measures would be either impractical to implement or ineffective over the short-term in restraining traffic in large metropolitan areas: (1) limiting vehicle ownership, fuel or mileage by regulation; (2) completely banning the use of major vehicle categories (e.g., private passenger cars, taxis, trucks) in major portions of any large metropolitan area; and (3) imposing higher sales taxes and/or registration fees upon vehicles used in particularly high pollution areas. Accordingly, we do not give these measures attention here. For a discussion elsewhere, see Institute of Public Administration, Governmental Approaches to Automobile Air Pollution Control (Washington, D. C.: 1971), Chapters 2 and 3.

[3] Administrative action to reduce motor vehicle storage capacity, however would usually result in increases of market-set parking rates, which, in turn, would have a reinforcing effect.

Table 6-1

MOTOR VEHICLE RESTRAINTS

Restraint	Description	Experience[1]	Results
Regulating Parking	Reduce by administrative action motor vehicle storage capacity, off-street and/or on-street parking in or near high pollution areas.	Some large cities have moved to control the construction of additional parking garages in downtown areas. However, other off-street parking (e.g., spaces in commercial buildings made available to employees) are usually outside of municipal control. On-street parking has been controlled in relatively few areas, except during peak hours.	Would reduce motor vehicle use in high pollution areas, and to some extent to and from them. This reduction, particularly if combined with controls over on-street parking, could also significantly improve traffic flow. However, through and circulating traffic would not be reduced, and might even be encouraged.
Pricing Parking	Impose parking prices for off-street and/or on-street parking in or near high pollution areas.	Increased off-street parking charges have occurred in virtually all metropolitan areas as demand exceeded supply. However, nominal charges (well below those for off-street parking in the same vicinity), are still in effect for most on-street parking. Moreover, most off-street spaces are still allocated outside the market mechanism (e.g., to employees, residents). Parking meters are still the major method of charging for on-street space.	
Regulating Road Use	Reduce by administrative action road network used (e.g., through pedestrian malls, vehicle free zones) in or near high pollution areas.	Some 24 U.S. cities have introduced such schemes (mostly on an experimental basis) in recent years.[2]	Would reduce or eliminate motor vehicle use in high pollution areas, and to some extent to and from them. However, would create host of transportation problems (e.g., fringe parking, goods delivery, improved access and internal circulation) and possibly greater congestion and accompanying motor vehicle emissions on immediatel adjacent local streets and arterials.
Pricing Road Use	Impose charges for motor vehicle use of selected portions of urban street networks in or near high pollution areas	Toll collection facilities in and around Baltimore, Boston, Chicago, Jacksonville, Kansas City, Miami, New York City and Philadelphia. Other techniques for imposing road pricing are currently available, as summarized in text, but have only been tried in limited applications or not at all.	

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1. Most experience with motor vehicle restraints has been motivated by objectives other than air pollution control (e.g., reducing congestion, minimizing motor vehicle-pedestrian conflicts, enhancing the esthetic and commercial appeal of central city areas, and, in the case of parking charges and toll collection, raising revenues). However, particularly in some large cities growing concern about automobile air pollution has given rise to increasing public support for curbing motor vehicle use.

2. Atchinson, Kan.; Cincinnati, Ohio; Williamsburg, Pa.; Columbus, Ohio; Dennison, Texas; Denver, Colo.; Fresno, Calif.; Grand Junction, Colo.; Kalamazoo, Mich.; Knoxville, Tenn.; Miami, Fla.; Miami, Okla.; Minneapolis, Minn.; Montevideo, Minn.; New York, N.Y.; Patterson, N.J.; Pomona, Calif.; Providence, R.I.; Riverside, Calif.; Sacramento, Calif.; Stamford, Conn.; Tulsa, Okla.; Urbana, Ill.; Washington, D.C. See C. Kenneth Orski, "Vehicle-Free Zones in City Centers," (Cologne, Germany: Organization for Economic Co-operation and Development, October 1971).

which conceivably could be controlled by regulating parking: (1) on-street parking (available for short periods only where metered); (2) publicly available off-street parking (whether publicly or privately provided); and (3) privately available off-street space.

Present policy (though not necessarily enforced) in most municipalities is to prohibit on-street parking whenever and wherever it obstructs traffic movement, typically along major arterials during commuting hours. Rationing the rest of on-street parking is usually accomplished by parking meters or other enforcement aids such as permit stickers and (in Europe) parking discs. Off-street parking (especially in retail areas) is now encouraged in most municipalities by providing municipal garages and/or requiring parking space in new commercial buildings. Both policies have made available all-day parking and thus served to stimulate motor vehicle use, particularly where the municipal spaces are provided below cost (i.e., subsidized).

In most metropolitan areas, some private property owners provide public parking for profit at market-set rates. Other private owners provide parking for their residents, employees and customers, either free or for charge. However, public, for charge parking services may not usually be offered without appropriate land-use permits. In the United States there have been few attempts, and none successful, to restrict use of private property for parking of employees, customers, or residents.

Present policies for publicly available parking (both on- and off-street), however, are now under review in many metropolitan areas, and in some cases have been changed to take account of the limited existing street system and storage capacity. Some years ago, for example, the New York City Planning Commission "probably set a precedent for large cities by refusing to approve the construction of several parking garages to provide short-term parking at reduced rates for business and shopping purposes in midtown Manhattan."[1] More recently, the same city has increased its enforcement of on-street parking limitations. According to a recent account, each week some 1,000 motorists have their illegally parked vehicles towed away, resulting in a $75 fine.[2] Other cities have moved to limit existing on-street parking at certain hours to residents only, in an attempt to discourage parking on city streets by residents of outlying districts. Boston, for example, now limits all night-time street parking to city residents who display a special sticker on their windshield.[3]

Pricing Parking

Another approach to controlling the use, and to some extent, the amount and location of motor vehicle storage capacity would be through actions which raise parking prices to a level sufficient to discourage motor vehicle use at selected times in specified areas. Parking charges could be raised for the entire day (e.g., a relatively flat rate per hour) or for periods related to peak hours (e.g., high peak hour charges combined with lower off-peak charges).

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[1] Lyle C. Fitch and Associates, Urban Transportation and Public Policy (San Francisco: Chandler Publishing Company, 1964), p. 150. "The reason cited," this source observes, "was that these additional traffic generators would unduly further congest street traffic, and might actually reduce the total volume of movement into and out of the midtown area. The argument did not impress advocates of the midtown garages, including the midtown department stores. The Planning Commission would have been on stronger ground if it had been able to buttress its arguments with figures; unfortunately research techniques for producing such data have not yet been devised."

[2] "The Ban-the-Car Movement," Newsweek (January 4, 1971), p. 42.

[3] Ibid.

Furthermore, such increases could be limited to selected days (e.g., Monday through Friday). The potential effects of such pricing policies have been summarized as follows:

> A relatively high flat rate per hour will have the effect of discouraging all-day parking, especially by regular commuters, more short-period parking, since the demand for short-period parking for businesses or shopping purposes is apparently less elastic than the demand for regular all-day parking. However, if the charge is sufficiently high to reduce peak-hour congestion to acceptable levels, it may be excessively high for other periods, and discourage driving into the central area for shopping or business during periods when streets are well able to handle the traffic. In such cases, lower charges for off-peak parking are indicated. Low-cost short-term parking is frequently provided by merchants or public authorities, but with no reference to an overall policy of efficient traffic control.[1]

In principle, local governments might increase parking prices in either of two ways. First, a municipality might regulate prices for publicly-available parking spaces as it would regulate any public service utility regulation having the effect of raising parking prices. Or, municipalities could impose parking taxes, either with a flat rate or selectively as to location, day of the week or elapsed parking time.[2] The municipal taxation method appears particularly preferable where local revenues will be required for improved and expanded public transport, which would be required if any major motor vehicle restraints on private passenger cars are imposed.

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[1] Lyle C. Fitch and Associates, Urban Transportation and Public Policy (San Francisco: Chandler Publishing Company, 1964), p. 150.

[2] In October 1970, the city of San Francisco imposed a 25 percent tax on parking fees in non-municipal parking garages. The Washington, D. C., City Council is currently considering a similar tax. In both cases additional municipal revenue has been the primary objective, although air pollution control has been advanced as a complementary goal.

Regulating Road Use

In this category are a number of measures (e.g., pedestrian malls, vehicle-free zones) which, in effect, reduce the usable street network in high pollution areas. As a recent article points out, it has been only in the late 1960's that these measures have really gained momentum.

> Within the last several years the number of cities which have introduced traffic bans (on an experimental or permanent basis) has grown impressively. In Germany alone, twenty-eight cities have introduced traffic restraints and auto-free zones since 1967. A large number of pedestrian areas have also made their appearance in Dutch, British and other European towns. Perhaps the most widely publicized efforts have been those of Tokyo, Rome and New York City. Each of these cities has excluded traffic on a part-time experimental basis from portions of busy central areas; Tokyo from the Ginza, Shinjuau, Ikebukuro and Asakusa Districts, Rome from a number of its most famous piazzas, New York City from midtown sections of Fifth and Madison Avenues.[1]

In most cases, however, these projects have not had air pollution control as a major objective.

The same source indicates that the scale of existing measures to regulate road use can vary considerably, and in most cases has been admittedly modest.[2] More recently, however, larger scale projects have been attempted, primarily in Europe. The German city of Essen, for example,

> has recently extended its network of pedestrian streets and malls to create a car-free zone nearly 1 km. in length and nearly 300 meters in width. The Hague and Düsseldorf both possess traffic-free zones which span a

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[1] C. Kenneth Orski, "Vehicle-Free Zones in City Centers," (Cologne, Germany: Organization for Economic Co-operation and Development, October 1971), p. 3. According to an inventory of such measures appended to this article, road restrictions are now being tried in some 156 cities around the world including 24 in the United States.

[2] Ibid., p. 7.

> total of 2.4 km. and 3.4 km. of streets, respectively. Copenhagen's Strøget, a highly successful venture in traffic exclusion, is 1,080 meters long; a further extension in 1968 has added another 300 meters of adjoining streets to the pedestrianized area. By far the most ambitious scheme is that of the city of Vienna, which is contemplating the creation of a vast traffic-free central zone with a diameter of about 1.2 km. In as much as the area would be too large to be served exclusively by movements on foot, non-polluting taxis and mini-buses running on liquid gas would be allowed to circulate within the exclusion area.[1]

In addition to their scale, regulating road use can be varied according to the degree of restriction desired. Proceeding to increasingly restrictive measures, one could have: (1) private passenger cars excluded during certain hours of the day or days of the week (e.g., 10:00 a.m. to 4:00 p.m.); (2) some private passenger cars excluded but others (e.g., those operated by area residents or doctors on call) permitted; (3) all private passenger cars excluded from specific zones (e.g., pedestrian malls). Obviously, both the scale of the measure and the degree of restriction should be tailored to meet a given city's circumstances.[1]

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[1] C. Kenneth Orski, "Vehicle-Free Zones in City Centers" (Cologne, Germany: Organization for Economic Co-Operation and Development, October 1971), p. 9. A large-scale series of experiments with motor vehicle restraints was recently conducted in Marseilles, France, where a total ban on parking was imposed in the core of the city, covering about .25 square kilometers. At the same time, 9 kilometers of exclusive bus lanes were added to improve existing bus service,and all public transport was provided free of charge during one day to test the response of free service. For details see, C. Kenneth Orski, "Car-Free Zones and Traffic Restraints: Tools of Environment Management," Report prepared for the 51st Annual Meeting of the Highway Research Board (Paris, France: Organization for Economic Co-Operation and Development, 1972).

Vehicle-free zones have also been implemented in Florence (which has banned cars from a 40-block area in its historic center), Munich (which has created a large traffic-free zone as part of its preparations for the Olympic games), and Brussels (which is conducting a 7-month experiment to ban parking altogether in the Grand'Place, except for tourists, buses and trucks during limited delivery hours). New York City is currently contemplating several vehicle-free zone possibilities, the most ambitious of which would convert a 15-block segment of Madison Avenue between 42nd and 57th Streets into a permanent pedestrian mall.

One of the most interesting approaches to regulating road use (an approach which combines motor vehicle restraints with measures to bypass thru traffic) has been tried in Bremen, Germany, and in the Swedish city of Gothenburg. In recent years, these cities have been divided into quadrants, and physical barriers have been constructed between these quadrants, thus making thru traffic within the city impossible (except for emergency vehicles -- fire, ambulance and so forth -- and public transport, which are permitted to pass between quadrants). In effect, each quadrant has become a self-contained precinct with only local circulation allowed. All other traffic must use a circumferential road, leaving and entering each quadrant at designated locations. This, in effect, reduces the use of vehicles for downtown circulation and increases walking.[2] As indicated in a subsequent section of this chapter, the Gothenburg approach appears to have achieved important air pollution reduction results, as well as other ancillary benefits.

Pricing Road Use

Road pricing to raise revenues (not to control traffic) currently exists in the United States and abroad, both by paying for highway construction through fuel taxes[1] and through special tolls imposed for high-cost bridge, tunnel and freeway facilities.

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[1] In addition, selective restrictions could be applied by type of vehicle. For example, German cities with pedestrian precincts commonly employ a ban on commercial vehicles making deliveries between the hours of 10:00 am and 8:00 pm. In a number of cities, thru traffic is required to use bypasses or specified routes, and in some residential neighborhoods, commercial traffic is excluded all together.

[2] For further details on the Gothenburg approach see Chapter 4, "Bypass Thru Traffic."

The toll collection approach is in wide use at present. Applied by public authorities (and occasionally local governments) operating river crossings or high capacity highways, tolls are levied to recover the costs of these particular facilities from the motorists actually using them. In contrast to fuel taxation, whereby motorists pay "averaged" prices for road use, toll collection imposes differing charges which can be varied according to the cost of the specific facility and how many times it is used.

While tolls are usually thought of in connection with turnpikes and intercity highways (which are closed to all users except those paying the toll), and are further known to be a relatively inefficient means of raising highway funds in lieu of taxes, the fact remains that tolls are widely levied in high density urban locations. Consequently, they are certainly a feasible means of road pricing in order to control the use of motor vehicles in areas of high automobile air pollution. All experience with toll collection, however, has been for revenue raising purposes, not to control motor vehicle traffic. Thus, toll authorities have traditionally adjusted rates so as to maximize revenues, not to reduce traffic. Among the large cities with toll facilities on major entry points for high capacity highway links leading in towards the

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[1] As a means of controlling traffic, fuel taxation would be a very blunt instrument and hence, inappropriate except for very large areas. Furthermore, fuel taxation which makes no distinction between peak and off-peak hours and high-and low-cost facilities would be objectionable on other grounds.

CBD are Boston, New York City, Philadelphia, Baltimore, Chicago, Kansas City, Jacksonville and Miami.[1]

In addition to the above, a number of other methods for imposing road pricing are possible, including a congestion pass approach (e.g., using stickers for tickets), manual or automatic scanning, metering, and so forth. Although a congestion pass approach shows promise for near term application,[2] most other methods presuppose continuous or intermittent monitoring of all vehicles on the road and will probably not be ready for widespread application before the end of this decade.

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[1] In considering how toll collection facilities might be used for pollution control purposes, perhaps the New York City case (where traffic volumes are highest) is the most instructive. All four of the highway connections to Staten Island (population approximately 500,000) are tolled. Of the ten crossings over the Hudson and East Rivers linking Manhattan to the New Jersey and New York counties, six are tolled. In addition, one of the bridges over the much smaller Harlem River is tolled. Two additional East River crossings between the Bronx and Queens are tolled. In sum, within the city of New York, and amidst conditions of extremely high volumes and congestion, there are thirteen toll collection points, all located on arterial and expressway facilities providing for major access or linkage traffic. In addition, the highest capacity highways in New Jersey, New York and Connecticut which both link the city to and serve between major suburban nuclei are tolled. These facilities include the Turnpike and the Garden State Parkway in New Jersey, the Saw Mill River Parkway, New York State Thruway, Hutchinson River Parkway, and New England Thruway in the state of New York, and the Wilbur Cross and Connecticut Turnpike in Connecticut. In fact, the only toll-free parkway going north from New York City is the Bronx River Expressway.

Using these existing toll facilities for road pricing with the more pervasive coverage which would presumably be required for reducing motor vehicle miles traveled is one possibility. From an air pollution control point of view, if tolls at all of these existing facilities could be collected without excessive congestion (and emissions), there is no doubt about the feasibility of using controls for this more expanded kind of road pricing.

[2] Under this approach motorists could be charged according to place (and perhaps time) of car use. Concentric control zones could be drawn to coincide with areas of traffic density and air pollution. In a given metropolitan area the central business district might constitute the inner zone, central city an intermediate zone, and outlying suburbs a third. Motorists could purchase distinctive stickers which license them to drive and park in a specific zone. Assuming congestion and pollution were most severe at the center, the sticker cost could be highest in the central zone and decrease for outlying ones. A congestion pass permitting vehicle use in the central zone would permit vehicles to be driven in areas of less stringent control, although the reverse would not apply. Any vehicle without an appropriate sticker would be fined or towed away.

Air Pollution Control Potential

At some point on the scale of regulation or price increase, motor vehicle restraints of the sort discussed above would unquestionably reduce traffic volume in downtowns or any other selected area. Traffic congestion and its concomitant air pollution (not to mention noise pollution and other undesirable motor vehicle externalities) would also be reduced. Available air quality monitoring data from the experience to date have been limited to sampling concentrations on streets and/or near major roadways, but indicate that motor vehicle restraints can have a powerful effect on improving local conditions.

As would be expected, the most dramatic reductions have been achieved from total ban. During the first phase of the Marseilles experiment noted earlier, mean values of carbon monoxide dropped from 18.8 to 3.6 ppm when all vehicles except taxis and buses were excluded from the central area.[1]

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[1] The average of seven readings per day (8:00 a.m. to 6:00 p.m.) at four locations. Source: Association pour la Prevention de la pollution atmospherique, Comite-Provence, cited in C. Kenneth Orski, "Car Free-Zones and Traffic Restraints: Tools of Environmental Management," Paper prepared for Presentation at the 51st Annual Meeting of the Highway Research Board (Paris, France: Organization for Economic Co-operation and Development, 1972), p. 6.

During the second phase of the experiment, when parking was totally banned in the core of the city, but traffic was allowed to move freely, mean values went from 18.8 to 11.6 ppm.[1]

Data to determine the effects of motor vehicle restraints on a larger scale (e.g., concentrations in the central city or on a metropolitan area-wide basis) are not available. Consequently, we must confine the following to some general comments about the air pollution control potential of various motor vehicle restraints.[2]

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[1] The average of seven readings per day (8:00 a.m. to 6:00 p.m. at four locations. Source: Association pour la Prevention de la pollution atmospherique, Comite-Provence, cited in C. Kenneth Orski, "Car Free-Zones and Traffic Restraints: Tools of Environmental Management," Paper prepared for Presentation at the 51st Annual Meeting of the Highway Research Board (Paris, France: Organization for Economic Co-operation and Development, 1972), p. 6.

[2] Apart from a few small-scale experiments (e.g., the closing of part of Madison Avenue in New York City) the only experience with limiting motor vehicle use on a large scale in the United States was during the Depression and World War II. Data on motor vehicle registration and transit ridership during that period indicates the effects of an adverse economy on motor vehicle and transit use.

With the commencing of World War II, the construction of highways, mass transit vehicles and private passenger cars was almost completely halted. Furthermore, gasoline and tire rationing were in effect. What with these drastic restrictions on automobile use and the high pace of industrial development, transit ridership dramatically increased. In 1945, patronage stood at over 23,000,000,000, or almost twice that of 1935. However, conclusion of the Second World War signaled the end of this reprieve for the transit industry. More roads and streets were built; the war economy swelled the purse of consumers and manufacturing might, acquired by the auto industry in producing war materiel, was shifted to motor vehicle manufacturing. The result was that in 1946, there were 28,000,000 vehicles registered; in 1956, over 54,000,000 were registered; and today, there is almost one vehicle for every two people in the United States. Not only has the transit industry not withstood the competitive assault, but it has found itself being held back by one of the major service deficiencies of the motor vehicle system -- congestion. For further discussion, see Institute of Public Administration, "Evolution of Urban Public Transportation in the United States," Appendix A to "The Present Condition and Characteristics of the Transit Industry and How They Evolved," draft report (Washington, D. C.: Institute of Public Administration, 1971).

Regulating and Pricing Parking

Since motor vehicles coming into high pollution areas must park somewhere (unless they are traveling through) their movement may be restrained by reducing (or making more expensive the use of) parking facilities. From the standpoint of air pollution control, the use of parking controls has some limitations. Thru and circulating traffic, which sometimes constitutes a relatively large proportion of total traffic, even during peak hours, may not be restrained; indeed, if congestion in central areas is reduced, such traffic may even be encouraged.[1] The effectiveness of parking measures in reducing emissions may also be limited by difficulties in controlling all parking space[2] and various political obstacles in implementing comprehensive parking controls.[3]

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[1] As noted in Chapter 4, the solution to the thru traffic problem would appear to be a bypass for thru traffic via circumferential routes or other means. However, if thru drivers choose to use central city streets instead, parking controls will not deter them.

Circulating traffic consisting of taxis, trucks and other service vehicles, can together account for the majority of vehicle miles traveled in some downtown areas (e.g., midtown Manhattan). To cite another example, some commuters may find it desirable to have a member of the family drive them to work, drop them off, and return home with the car. If a similar sequence occurs at the end of the day, parking controls could conceivably result in doubling the vehicle miles traveled of some motor vehicles. Although there are no empirical data to allow an estimation of the additional vehicles miles traveled which would be generated, experienced traffic engineers maintain that cordon counts on rainy days are approximately 15 to 20 percent above what they are at other times, for similar reasons.

[2] Private parking provided free of charge accounts for half of total parking space in the CBD's of many major metropolitan areas. Comprehensive parking controls over already existing space provided by private firms and government agencies would be difficult to enforce and would probably require new legislation.

[3] These problems are discussed below under "Institutional Feasibility."

In sum, there are marginal parkers in any area who may be removed by making parking spaces scarcer and/or more costly. The scarcer and higher, the greater the number removed. However, the above limitations suggest that parking measures are probably but a second-best solution for purposes of air pollution control, the optimal one being to regulate or price motor vehicle use (i.e., entry, exit and operating time in heavily polluted areas).

Regulating and Pricing Road Use

In principle, the application of road use restrictions and pricing (e.g., a charge for motor vehicle use in certain areas -- and perhaps during certain times -- of high pollution concentrations) would be the most effective means of restraining motor vehicle use.

Some available evidence suggests that road use restrictions (specifically traffic bans) are indeed effective measures for reducing motor vehicle air pollution, at least locally, at the street level. In New York City, the closure of Fifth Avenue to traffic in the summer of 1970 resulted in a reduction of carbon monoxide concentrations from 30 ppm to 5 ppm.[1]

In Tokyo, Japan, exclusion of motor vehicle traffic from the Ginza, Shinjuku, Ikebukuro and Asakusa Districts resulted in important carbon monoxide reductions, as summarized in Table 6-2. Preliminary evidence also suggests that the Gothenburg approach, described above, is effective:

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[1] Unfortunately, however, close inspection of the New York City data suggests several reasons to be less than sanguine about the actual emission reduction achieved. For one thing, monitoring for the experiment was inadequate. For another, it appears that although carbon monoxide concentrations were reduced on those streets closed to traffic, the concentration levels were higher for immediately adjacent avenues which bore the brunt of additional congested traffic movement.

> Goteborg's experience has shown that this traffic management approach can reduce circulation by as much as 50 percent. Although the scheme has been in operation only since August 1970, it has already had a number of beneficial environmental effects: there has been a reduction of 5 percent in accidents; mean concentrations of CO in the Central Business District have lowered from 30 ppm to less than 5 ppm, and noise levels went down from 75 dba to 72 dba.[1]

As noted earlier, these measures appear effective in the immediate areas affected, although a number of larger issues are unresolved.

For one thing, the appropriate scale for such efforts is far from clear, as suggested above with respect to the New York City experiment. Nor is it clear whether total trips to some boundary of the restricted area could be reduced. Isolated pedestrian malls may reduce local air pollution concentrations but fail to achieve an important improvement in air quality for the entire CBD. Indeed, air quality may worsen because of congestion on adjacent arterials.

On the other hand, large scale projects cause their own kinds of problems:

> Closing streets to traffic on a larger scale very soon begins to pose a host of transportation-related problems; fringe parking, improved access, goods' delivery, traffic rerouting and internal circulation. It is no accident that existing pedestrian precincts seldom exceed 400 to 500 meters in length; this may be the maximum distance which it is felt an average shopper is willing to negotiate on foot. Beyond it, some mechanized circulation system may be necessary.[2]

These transportation-related problems, of course, would have to be worked

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[1] C. Kenneth Orski, "Vehicle-Free Zones in City Centers," (Colgone, Germany: Organization for Economic Co-operation and Development, October 1971), p. 10.

[2] Ibid., p. 8.

Table 6-2

EFFECT OF TRAFFIC BANS ON CARBON MONOXIDE CONCENTRATIONS IN TOKYO

	ppm of CO		
Sampling Station	Before[1]	After[2]	Remarks
Ginza			
Okura Building	14.2	2.9	Average of 5 hourly readings (1:00 p.m.-6:00 p.m.)
Victor Building[3]	5.5	2.4	
Gas Hall	5.4	2.3	
Shinjuku			
Kome Theatre	2.2	1.2	Average of 8 hourly readings (11:00 a.m.-7:00 p.m.)
Yamaichi Sec. Bldg.[3]	9.8	2.3	
Electro-board	11.3	2.3	
Ikebukuro			
Parco	9.5	3.5	Average of 7 hourly readings (12 noon-7:00 p.m.)
Seibu Dept. Store	6.7	3.0	
Sumitomo Bank	5.7	4.2	
Asakusa			
Rokku	1.7	1.9	Average of 9 hourly readings (10:00 a.m.-7:00 p.m.)
Ward Office Branch	3.2	2.2	

Source: Traffic Division, Metropolitan Police Department, Tokyo, Japan (courtesy of Shinji Nishida, Chief, Traffic Regulations Section) as cited in C. Kenneth Orski, "Vehicle-Free Zones in City Centers," (Cologne, Germany: Organization for Economic Co-operation and Development, October 1971), p. 5.

1. Before: July 26, 1970 (wind velocity: 3.9 m/s)

2. After: August 2, 1970 (wind velocity: 3.3 m/s)

3. Survey by automatic recorder; in all other locations, hourly sampling and analysis by infra-red method.

out on a case-by-case basis, taking into account the scale of the project, the existing street system, the availability of public transport and other city-specific factors.

In conclusion, road pricing, to the extent it can be implemented in a satisfactory manner, offers a more effective way to reduce emissions than parking controls or restrictions on portions of the street network. Sufficiently high charges would reduce the total number of motor vehicle trips made, but if charges were adjusted by day of the week and hour of the day, they could be selectively applied and would not affect vehicle operation considered unobjectionable (weekends, evenings, and perhaps during off-peak hours). Finally, and perhaps most importantly, substantial revenues would be generated for the improvement of public transport which would seen a concomitant if urban mobility is not be seriously reduced.

The practicability of implementing road pricing remains an untested proposition. Nevertheless, the air pollution control potential of road pricing (as well as other possible ancillary benefits) argue strongly for further exploration of the concept to indicate whether and how such a system could be instituting to control motor vehicle use in the core areas of central cities.[1]

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1. Among the issues which ought to be addressed are: (1) what would be the public's response to road pricing; (2) what kinds of operating costs would be associated with alternative collection systems; (3) what would be the feasibility and impact of differential pricing policies; (4) what would be the social and economic consequences (e.g., on downtown business and employment and on individual road users); (5) what kinds of public transport service would have to be provided; (6) what kinds of institutional problems (e.g., coordination among neighboring jurisdictions) might be encountered. If initial indications are favorable, a demonstration would be desirable to determine the effects of road pricing schemes on congestion and air quality.

Maximum Feasible Emission Reduction

The emission reduction potential of motor vehicle restraints is a function of the severity of those restraints. If widespread road pricing were implemented, or if overall parking space were significantly reduced, motor vehicle miles traveled (and hence, emissions) would decrease. Conversion of large central city areas into vehicle-free zones could have an even more dramatic effect. Such extensive restraints on motor vehicle use in major portions of any metropolitan area, however, are clearly not feasible within the next five years.[1]

Estimates of the emission reductions which might be reasonably expected from less severe restraints are not easily arrived at since no systematic study has been made of the price elasticity of motor vehicle use.[2] Our best judgment is that (taking parking controls as a surrogate for motor vehicle restraints) if parking rates were doubled for a city such as Washington, D. C., the reductions in motor vehicle traffic (and emissions) would be minor, probably not to exceed 5 percent. Under a comprehensive parking control program (whereby existing rates for all spaces were tripled or quadrupled) an overall reduction in motor vehicle traffic of from 20 to 25 percent might be achieved (assuming, as always, that public transport would be importantly improved). Such a program would appear to be the upper limit of practical action at present.[3]

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[1] In addition to practical problems noted above, the political opposition (e.g., from automobile owners' associations, downtown merchants) would be enormous. Furthermore, it is difficult at this time to see where strong political support for complete bans would come from. For further discussion see below, "Institutional Feasibility."

[2] Price elasticity here refers to the percentage change in motor vehicle use accompanying a change in the cost of using the motor vehicle (either investment, operating or time costs).

[3] Further discussion of these judgments, as well as a review of the data upon which they are based can be found in Appendix F of this report.

Institutional Feasibility

Any assessment of the institutional feasibility of motor vehicle restraints must begin by acknowledging the significant shift in public sentiment toward the automobile in recent years. In a recent book, Aspirations and Affluence, a team of analysts from the University of Michigan Survey Research Center observed that studies carried out in the late 1960's "indicate that car has increasingly become a means for serving important ends, rather than the highly priced possession it once was in the United States and still is in much of Europe."[1] These changes in attitude may make Americans less attached to their cars and hence more amenable to motor vehicle restraints in some core areas of central cities. Attitudes alone, however, will not appreciably affect motor vehicle use, at least in the short term.

Motorization rates continue unabated and there is a rising demand for second and third cars (although many of these are smaller American cars or imported vehicles). Likewise, the proportion of households without a car continued to decline in the 1960's and is now only about 20 percent. Finally, and most relevant to this study, the travel patterns of all metropolitan areas are increasingly characterized by dispersed trip ends, which cannot be readily served by most public transport systems. Americans may appear less enamored of their automobile, but they are hardly less reliant on it.

Nevertheless, it does seem reasonable to assume that public sentiment will continue to grow in favor of curbing at least some motor vehicle use in congested areas of large cities. At present most motorists probably realize that the downtown area dictates a high level of control over motor vehicle movement.[1] A number of developments -- relatively slow traffic movement and the many frictions caused by circulating traffic, parking and unparking, truck loading, and signalization, and heavy traffic volume -- already affect road users in downtown areas by restricting their freedom. Informal evidence such as exists seems to indicate that growing numbers of motorists are coming to regard curbs on motor vehicle use in some areas of central cities as inevitable, indeed desirable.

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[1] Dr. George Katona et al., Aspirations and Affluence, cited in Dan Cortez, "Autos: A Hazardous Stretch Ahead," Fortune, April 1971, p. 69.

At the official level, public discussion of motor vehicle restraints in the United States has changed dramatically during the past decade. In 1961, when the possibility of regulating motor vehicle use (through road pricing) was first advanced to the Federal Government in a national urban transportation study, one of the sponsoring agencies refused to release the report.[2]

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[1] Unfortunately, these statements are highly speculative since we are aware of no available behavioral research which tests driver reactions to various motor vehicle restraints. Most drivers probably accept and recognize the need for such restraints, at least in core areas. However, a sizeable number of drivers place their personal interests first and are willing to violate even existing regulations, to the detriment of drivers and pedestrians. If motor vehicle restraints are considered for implementation, it would be useful to develop information describing the best possible way of implementing these to obtain the highest level of acceptance by road users.

[2] A book based upon this study by the Institute of Public Administration, however, was subsequently published in substantially rewritten form. See, Lyle C. Fitch and Associates, Urban Transportation and Public Policy (San Francisco: Chandler Publishing Company, 1964).

Less than a decade later, statements in favor of curbing motor vehicle use in some central city areas have been made at the highest level of the U.S. Department of Transportation. For example, in his keynote address to the 1969 Pittsburgh conference on urban transportation, Department of Transportation Secretary Volpe stated:

> America must now accept the fact that the private automobile will not forever be the absolute monarch of our core cities. How and when this change will come about, we cannot yet say. But the means are not altogether obscure. We could make mass transit so attractive that habitual drivers would leave the highways. Some are convinced that dial-a-bus and other personalized modes will provide a breakthrough. We could tax cars entering the city in order to pay for police services, traffic control, parking, road repairs, and so on.
>
> More and more, the hallowed right to jump into our cars and drive them anywhere we please is being tallied against other community and individual values -- the need for elbow room, clean air, stable neighborhoods, more parkland, and many others. So far, we have sought sheer mobility above every other consideration; other needs have been neglected, and the social equation is clearly out of balance.[1]

Growing interest in regulating motor vehicle use is also evident in Congress, where on July 15, 1971, a bill was introduced in the House of

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[1] Proceedings, Fourth International Conference on Urban Transportation, Pittsburgh, Pennsylvania (March 10, 11, 12, 1969) cosponsored by the Pittsburgh Urban Transit Council and the U.S. Department of Transportation. Keynote Address by the Honorable John A. Volpe, Secretary, U.S. Department of Transportation, p. 8. Among other things, this statement was significant because it was the first major policy statement of the Secretary upon assuming office. More recently, see DOT press releases of August 27, 1970 and February 16, 1971.

Representatives to allow cities with a population over 200,000 to collect tolls or user fees on the freeways within their jurisdictional boundaries. According to its author:

> The purpose of this bill is to significantly reduce automobile pollution, which now accounts for more than 50 percent of all air pollution in our cities. This legislation would also provide an added source of income to cities and would require that commuters help pay their fair share for the services in the city which they use.[1]

The significance of these statements is that public discussion at the official level has proceeded to a point where motor vehicle restraints are now seriously contemplated in many quarters. Details on how these motor vehicle restraints would be applied in specific cities have been developed in only a few cases,[2] but in the coming five to ten years one can expect such plans to proliferate. In subsequent sections we assess the institutional feasibility of the more promising of these measures.

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1. Statement by the Honorable Les Aspin, Congressman of Wisconsin, in the House of Representatives, Thursday, July 15, 1971, Congressional Record, proceedings and debates of the 92nd Congress, 1st Session.

2. Among the jurisdictions furthest along in this regard is New York City which is currently considering a substantial reshuffling of midtown traffic patterns to meet federal air quality standards. The proposals, which are in various stages of consideration, include: (1) conversion of Park Avenue from 34th Street northward, Central Park West and all the Central Park drives to northbound traffic up to 110th Street during noon and evening rush hours; (2) the establishment of express bus lanes on Madison, Second and Third Avenues and 48th and 49th Streets; (3) a halt to taxi cruising in midtown, to be replaced by creation of depots and taxi stands; (4) control of truck deliveries in midtown to limit them, for instance, to between 10 a.m. and noon and between 2 p.m. and 4 p.m., and to organize fuller loads at depots, perhaps on West Side piers; and, (5) creation of pedestrian malls on Lexington Avenue, Broadway, 48th and 49th Streets. See, "Midtown Traffic Reshuffling Proposed," New York Times, December 13, 1971, p. 1.

Regulating Parking

From the standpoint of institutional feasibility, there appear to be at least three principal problems with the use of parking regulations[1] as a means of pollution control.[2]

First, there would be great difficulty in controlling all parking space, particularly already-existing space provided for employee parking by private firms and government agencies.[3] As indicated in Table 6-3, this "uncontrolled" parking accounts for about 45 percent or more of total parking in many CBD's.[4] New space may be limited by zoning and building restrictions.[5] as in the center

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[1] Public regulation, if any, of parking varies considerably from city to city. However, parking is generally an unregulated service, except insofar as municipally-owned parking facilities may serve to regulate prices.

[2] The following discussion draws upon Lyle C. Fitch and Associates, Urban Transportation and Public Policy (San Francisco: Chandler Publishing Company, 1964), pp. 150 ff.

[3] The present discussion concerns primarily off-street parking; curb-side parking, however, would also have to be controlled.

[4] Unfortunately, parking data were not available for any of the six cities for this study, although with the exception of Washington, D. C., there is no reason to assume the data would be substantially different.

[5] In most metropolitan areas, it has been traditional practice -- in an attempt to secure more adequate off-street parking -- to require that a minimum number of parking spaces be provided in or adjacent to new buildings. A reversal of this policy, which has been achieved only with some difficulty in most jurisdictions, is bound to be disputatious and time-consuming, and in any event would have little overall effect from an air pollution point of view during at least another decade. Regulation of private property would be another possibility. However, there have been very few attempts, and none successful, to regulate the use private owners make of their property for private parking. Private owners, for example, may provide parking spaces, free of charge, for their employees and customers, although they may not run a public, for charge, parking service without appropriate land-use permits. Regulating private provision of parking, especially for employees on the premises, would be a substantial new intervention in the private use of land, and would take considerable time to introduce and implement. No cities could be realistically expected to have an effective parking regulation of this type by 1977.

Table 6-3

WORKERS PARKING IN THE CBD: FREE AND PAID

	Parked Free	Percentage of Total	Paid to Park	Percentage of Total	Total
Philadelphia	14,568	57	11,801	43	24,649
Boston	14,397	48	15,791	52	30,188
Baltimore	7,313	46	8,582	54	15,895
Seattle	8,835	54	7,575	46	16,410
Milwaukee	23,092	74	7,983	26	31,075

Source: Wilbur Smith and Associates, Patterns of Car Ownership, Trip Generation and Trip Sharing in Urbanized Areas, prepared for U.S. Department of Transportation, Bureau of Public Roads (New Haven, Connecticut: June 1968).

of New York City, but if controls are imposed only on those having no access to private spaces, discrimination is introduced. The social and political consequences would have to be evaluated in each case. Second, public action to restrict the supply of space may afford excessive profits for parking operators by allowing increases in market-set rates. Capturing these excess profits for public purposes would be politically difficult in many cases (e.g., where parking lots in garages are operated predominantly by large firms). This suggests that taxes are a much more acceptable means of raising parking rates. Third, a policy of regulating parking space would encounter the staunch opposition of all those who would be brought under control, a not inconsiderable force. And there would always be pressure for special arrangements, protection of "grandfather rights" and so on. Again, this suggests the desirability of the pricing approach. No parking program of regulation would be anywhere near 100 percent effective, while a comprehensive parking space tax might reach 85-90 percent of all off-street spaces.

Pricing Parking

Imposing parking charges would be subject to some of the same institutional problems indicated above. However, it appears unquestionable that municipal corporations can either regulate prices for parking (as in the case of a public service or utility), or impose taxes upon parking which would have the effect of raising parking prices. Raising parking prices would be politically difficult, and would certainly involve confrontations between those raising charges and those whose interests are directly affected (e.g., retailers and office building owners).

Generally speaking, parking pricing appears preferable to parking regulation, in that the former can be differentiated according to impact (e.g., to discourage parking during peak hours but not for business purposes before and after peak hours). It is doubtful that the same ends could be gained and the same degree of control achieved (e.g., encouraging midday use) by enforceable regulatory restrictions. Furthermore, taxes appear to be a more attractive alternative because they supply municipal revenues which are always badly needed and will be particularly so in the event that important public transit improvements are required.

Regulating Road Use

Road use restrictions would limit the use of motor vehicles by direct, enforced, administrative action. Correspondingly, they are dependent upon police powers (or other enforcement) for their effectiveness; and this would appear to be a major institutional problem. From the legal standpoint, it appears that all municipalities have the authority to regulate road use, and in the event that existing authority were in some way inadequate, it could probably be obtained. Important legal problems, however, could well arise from court challenges by abutting property owners, who might claim that the value of their property had been reduced by limiting or preventing vehicular access without due process of law. Conceivably, some municipalities might have to make compensatory payment for such cases.

Pricing Road Use

Generally speaking, road pricing would encounter political and legal problems similar to those indicated above. As noted earlier, some techniques are available for imposing road pricing. The mechanics of implementing road pricing, however, are probably much less a problem than gaining widespread public acceptance to limit "freedom of the road," even in areas of high air pollution.

CHAPTER 7

WORK SCHEDULE CHANGES

Definition of Terms

In the present chapter, we consider changes in established work schedules (e.g., work staggering and the 4-day week). Both measures tend to spread work trips to and from major CBD employment centers more evenly over time, thus thinning out traffic at the height of rush hour and smoothing flows. In the case of the 4-day week, weekly commuting trips could be cut by a fifth, thus reducing total vehicle miles traveled.

Focus on work trips to the CBD can be justified for three reasons. First, in most cities the journey to work accounts for the bulk of peak hour traffic, hence by considering work schedule changes we are often dealing with the single most important travel pattern at those times. Second, because work trips are concentrated at peak hours, a reduction and/or temporal redistribution of trips would do more to reduce congestion (and accompanying emissions) than measures taken at other periods. Finally, the difficulties in developing schedule changes to modify trips for other purposes (e.g., shopping, business, recreation) are so great to preclude this possibility, at least for the short term.

Work schedule changes can be grouped into two broad categories: work staggering and the 4-day week.[1] The first makes no modification in length of the working day (i.e., elapsed time between authorized start and finish times, now currently 8 to 8-1/2 hours for most employees). However, starting and stopping times are shifted somewhat (e.g., instead

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[1] Both approaches are summarized in Table 7-1.

Table 7-1

WORK SCHEDULE CHANGES

Name	Definition	Experience	Effect
1. Staggered[1] hours	Change in work hour schedule whereby employees in a given employment center shift starting and stopping times somewhat, but within a relatively short range (e.g., instead of 9 to 5, from 8 to 4). No change in length of working day required; any shift in the morning is generally matched by a corresponding evening shift.	Implemented in some 60 American cities during World War II. Current projects include a number of federal agencies in and around Washington, D.C. and some 70 firms in Lower Manhattan.	Spreads traffic peaks. Increases vehicle speeds.
2. 4-Day week	Reduction of work week to four days. Generally, work week still consists of same number of hours as before, but with longer working days. Some noticeable trend to 35-37 hour work weeks as employers experience increases in productivity under new work schedules.	Since 1969, approach has been receiving considerable attention in the United States. As of late 1971, 658 firms have converted to this schedule. Conversion rate is now 4 firms per day nationwide.[2]	Reduces number of weekly work trips by 20 percent. Daily reductions range from none at all to two-thirds, depending on rotation of 4-day week. Spreads traffic peaks. Increases vehicle speeds.

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1. A variant of the work staggering approach, called "gliding work hours" (Gleitende Arbeitseit"), is being tried in Germany to provide congestion relief. This is essentially a "self-staggering" approach, with no fixed work schedule modifications. Rather, employees choose their work hours within an established time frame. Major German firms which have shifted include Messerschmitt-Bolkow-Blohm with 7,000 employees in Munich, Lufthansa in Cologne and the Federal Ministry of Transport in Bonn, as well as some 2,000 other firms. In the German experience, several of the larger employers have lengthened work days to 11 hours and allowed employees (who must punch time clocks) to put in 8 hours within an 11-hour period (i.e., select arrival and departure times within a 2-hour range at their own discretion). Thus, as with work hour staggering, the intent is to allow travel before or after peak hours (as well as to ease the strain on internal resources, elevators, parking lots, etc.).

2. Personal conversation with Riva Poor, March 1972. Riva Poor edits and publishes the authoritative news letter on the 4-day week, Poor's Workweek Letter (Cambridge, Mass.).

from 9:00 a.m. to 5:00 p.m., from 8:00 a.m. to 4:00 p.m.). The second modifies the overall working day by requiring longer daily hours, but for one less day per week.

Although the following discussion of work hour staggering is generally relevant to "gliding time" (see note to Table 7-1), a few important differences should be noted. First, employer concern for operating efficiency will probably be greater under the gliding time approach, since it has greater potential for economic disruption. Second, and of import for purposes of air pollution control, experience with gliding work hours has shown that only minimal changes tend to occur in travel patterns, and that these are generally to earlier hours. These two factors, of course, minimize the extent to which "gliding time" can spread the peak. In a study conducted by two large employers in Germany (after 13 months of operation in one case and nine months in the other), it was discovered that only 20 percent of the employees changed their hours from those previously worked. In both cases, the predominant shift was to earlier hours. It appears that, in addition to personal value preferences, a shortage of parking space for those arriving late was the underlying factor forcing shifts to earlier hours.

Air Pollution Control Potential

Spreading journey-to-work traffic (and its concomitant congestion) over peak hours could contribute significantly to reducing motor vehicle emissions in cities. During these two short periods of the day, existing roadway capacities are most strained.[1] Average vehicle speeds dwindle to less than 10 mph in many CBDs, and engine operating efficiency is further reduced by a large proportion of idling and stop-and-go traffic. In contrast, capacity for most off-peak hours is in excess of traffic demand. This very uneven distribution of trips over time suggests the desirability of "spreading out" the periods of peak utilization, thereby distributing traffic more evenly over time and improving traffic flows. In cities where work trips constitute a substantial portion of peak hour trips (e.g., 60 to 70 percent), a spreading out of work trips could conceivably afford substantial traffic relief.

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[1] It is not particularly meaningful to use maximum daily capacity as a measure of capacity since one peak-hour may account for more than 10 percent of total daily travel. Conversely, almost no trips may be made during other hours (e.g., between midnight and dawn).

Changes in work schedules (which determine to a large extent the departure and arrival times of vehicles in congested areas) could provide the means for distributing work trips more evenly over time. From an air pollution control standpoint, the resulting peak hour traffic would probably be more important for alleviating maximum one-hour carbon monoxide concentrations (the averaging time for federal secondary air quality standards) than eight-hour concentrations (the averaging period for federal primary air quality standards).[1] However, any reduction in peak hour traffic will generally improve traffic flows and hence result in reduced emissions. Traffic flows tend to improve because demand will be more evenly spread over existing capacity. In addition, there will be fewer traffic frictions in CBD areas as parking lot ingress and egress times are more uniformly distributed, and turning movements become less disruptive. This potential of work schedule changes is suggested in Figure 7-1, which displays the estimated percent of people starting work in the Manhattan CBD.

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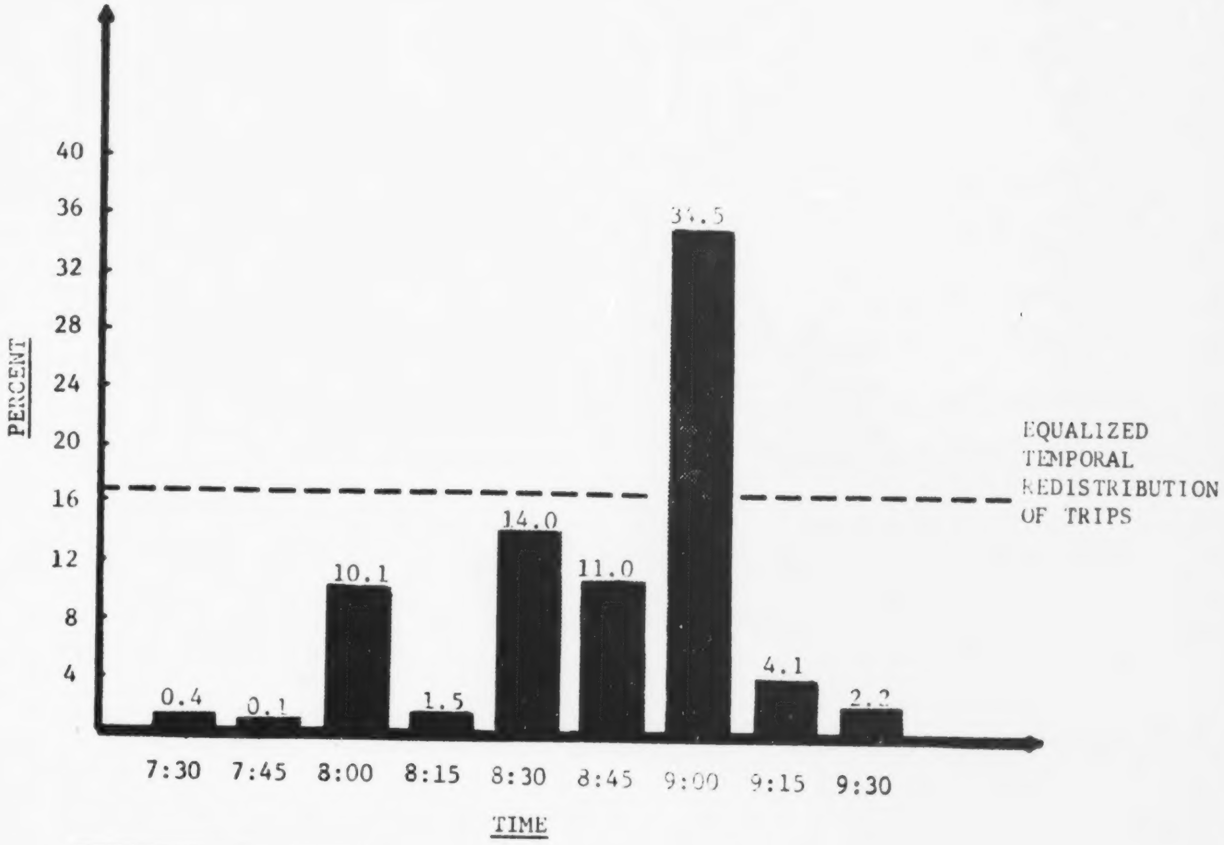
[1] Work schedule changes seem particularly appropriate for cities where morning winds are slow and the atmosphere generally stable, conditions that inhibit the dispersal of pollutants.

Figure 7-1

ESTIMATED PERCENTS OF PEOPLE STARTING WORK IN MANHATTAN CBD[1]



Concentration of work trips around 9 a.m. implies a corresponding concentration (i.e., congestion) of motor vehicles at this hour. However, for reasons discussed later, it is not necessarily correct to assume a "one-to-one" time relationship between work start schedules and traffic congestion. In the case of Manhattan (used here solely for purposes of example) very few work trips to the Manhattan CBD are actually made by private passenger car. Starting times are probably more widely distributed in New York City than elsewhere.

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[1] Lawrence B. Cohen, Work Staggering for Traffic Relief: An Analysis of Manhattan's Central Business District (New York, Praeger, 1968), p. 163.

As shown in Figure 7-1, a total of 82.9 percent of the work force starts between 7:30 and 9:30 a.m., with the principal concentrations (in descending order of importance) occurring at 9:00, 8:30, 8:45, and 8:00 a.m. Distribution of this traffic uniformly over the five half-hour time intervals would make optimal use -- from a traffic operations and air pollution control standpoint -- of existing roadway and transit capacity. For example, using data cited above, if 82.9 percent of work force starts were equally divided by give, there would be 16.6 percent in each one half-hour interval (a level represented by the dotted line). Distribution of work force starts would not have to be uniform, however, for significant gains to be realized. For present purposes, it is sufficient to say that within the five intervals outlined above, there is considerable latitude to facilitate re-scheduling and effect transportation relief of varying degrees.

In addition to improving traffic flows, the 4-day work week could contribute to reducing motor vehicle emissions in another and perhaps more important way; by reducing total work trips. Conceivably, each commuter could reduce his journey-to-work travel by two trips per week under a 4-day week, and an approximate 20 percent reduction in vehicle miles traveled (associated with the journey to work) could be achieved. Furthermore, if the working week is extended one day (i.e., Monday through Saturday, as is frequently observed with 4-day schedules), improvements in traffic flows could be even more considerable.

Staggering Work Hours

Assuming work staggering could be implemented -- an assumption which appears reasonable on the basis of available studies[1] -- how effective would work staggering be in reducing motor vehicle emissions? Little has been attempted in the way of systematic analysis of actual experience under staggered hours. Most after-the-fact evaluations go only so far as to indicate that "congestion levels on the streets were deemed bearable" as a result of the program.[1] Other studies, such as one for New York City,[2] concentrate almost exclusively on mass transit (as opposed to motor vehicle traffic) congestion relief as a measure of effectiveness.[3] The Lower Manhattan Study, however, did seek to obtain vehicular counts at the Brooklyn-Battery Tunnel and Battery Parking Garage. Little change was observed at these locations as the result of staggered hours, primarily (the authors indicated) because the number of participants in the program at the time of the study accounted for only a small proportion of total journey to work trips in the area.

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[1] Previous experience and recent experiments in the United States and in Germany indicate that work hour staggering is feasible. For further discussion, see below, "Institutional Feasibility."

Insofar as transit relief can be considered indicative of the success in spreading the peak, it should be noted that many work staggering studies, both a priori and ex post facto, have concluded that subway congestion in New York could be substantially relieved. In the Lower Manhattan Anniversary Study, for example, it was determined that passenger counts at the three busiest subway stations in lower Manhattan

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1. Chester Roy Julian, "Staggering Work Hours to Ease Existing Street Capacity Problems," a paper prepared for 1971 World Traffic Engineering Conference; Montreal, Canada (September 1971), p. 38.

2. Downtown-Lower Manhattan Association and the Port of New York Authority, "Staggered Work Hours in Lower Manhattan, First Anniversary Report," April 1971.

3. Work hour staggering for mass transit (particularly subway) congestion relief was studied in New York since over three-quarters of people entering the Manhattan CBD on a typical business day between 7:00 and 10:00 a.m. use subways and buses. In this connection, since fewer vehicles are needed to service a more uniform demand level, work hour staggering could conceivably improve mass transit service and ridership levels by increasing schedule frequency and serving additional routes.

showed a traffic decline of approximately 6 percent in the peak ten minutes on two lines. Furthermore, peak hour congestion on the Port Authority Trans-Hudson (PATH) was significantly reduced as a result of the program. For the PATH system, passenger counts during the evening peak 15-minute period at the Hudson Terminal declined by some 1,000 (from 7,500 to 6,500), a reduction of about 15 percent. Passenger entrances into the Hudson Terminal in the more lightly traveled 4:30 to 4:45 period rose by nearly 50 percent.[1] These observations are graphically depicted in Figure 7-2, which clearly shows a spreading of the p.m. peak hour under a work staggering program for an almost identical volume of riders.

The effectiveness of a work hour staggering program is highly dependent on the number of "controllable" employees who are (1) within the study area; (2) travel during the peak period; and (3) work for an identifiable number of major employers. The last consideration is crucial since the complexity in designing an effective staggered working hours plan[2] and the absence of comprehensive statistical records regarding

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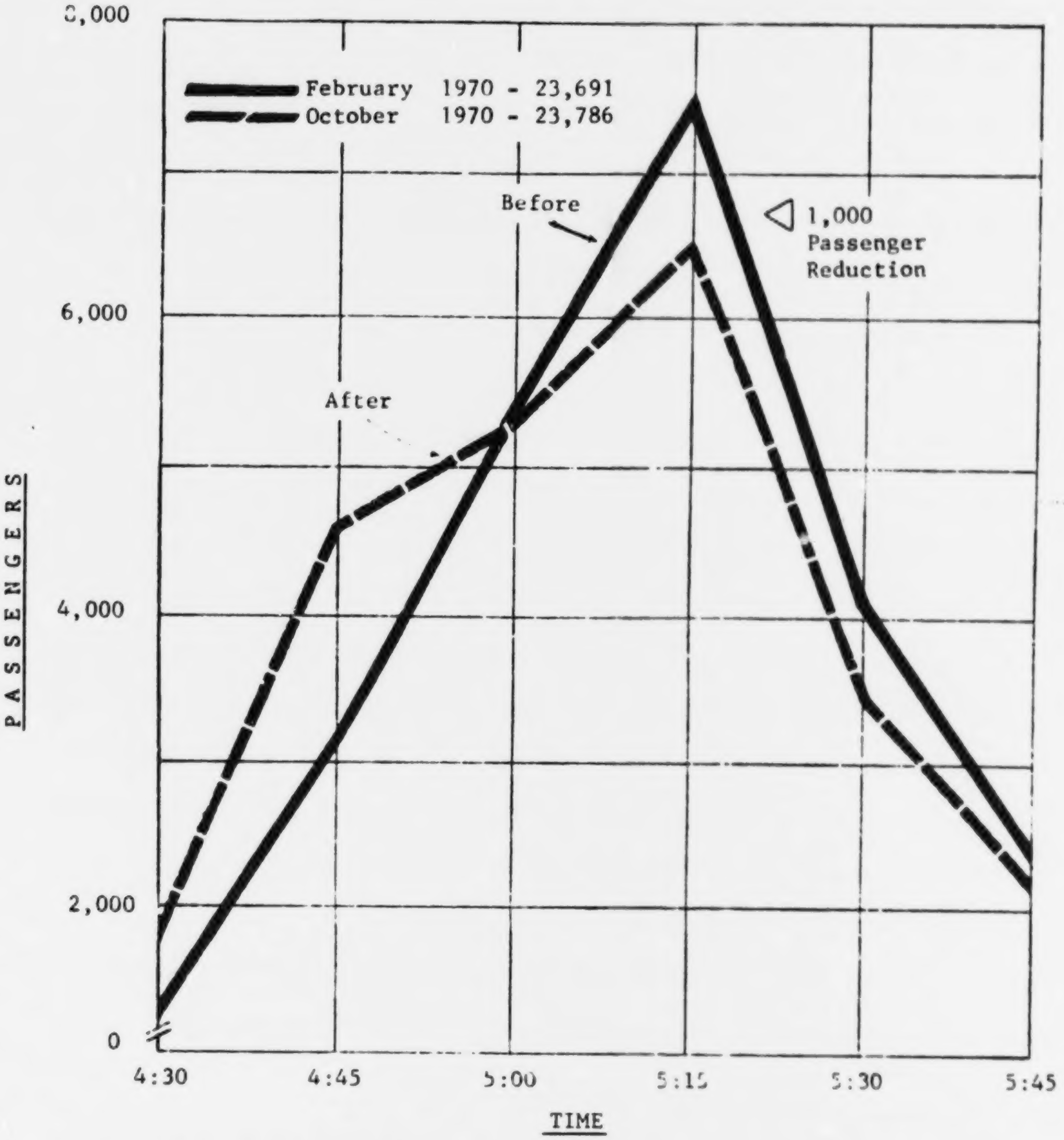
[1] Downtown-Lower Manhattan Association and the Port of New York Authority, "Staggered Work Hours in Lower Manhattan, First Anniversary Report," April 1971, p. 2.

[2] A work staggering program must typically take into account a number of considerations, among which are (1) the number of employers and employees effected; (2) the extent of work schedule changes; (3) the spatial distribution of trip origins and destinations; and (4) the differential effects on morning and afternoon peaks. Usually, these complex considerations can be evaluated only for a small set of employers and employees, unless resources are available and sophisticated computer simulation used. In this regard, the Atlanta Staggered Hours Study, after detailed investigation, chose only four major employers (employing some 11,000 people) for suggested participation in the program. Nevertheless, the study projected "significant" congestion

(Continued on page 7-10)

Figure 7-2

EFFECTS OF STAGGERED WORK HOURS
ON P.M. PASSENGER VOLUMES
AT PATH HUDSON TERMINAL



Source: Downtown-Lower Manhattan Association and the Port of New York Authority, Staggered Work Hours in Lower Manhattan, First Anniversary Report, April 1971.

employer characteristics typically require that the number of employers participating in the program be small. These considerations also imply that for those cities in which the proportion of peak travel attributable to the journey to work is relatively low (e.g., Los Angeles, San Francisco), the number of "controllable" employees is correspondingly low, and may not allow design of an effective work staggering program.

At the heart of designing a staggered hours plan (and estimating the air pollution control potential) are problems of forecasting traffic volumes at various intervals of the peak period. Paramount among the difficulties is that work hour schedules only tell when employees are required to be at work, not when they actually arrive. There is considerable evidence in many cities that informal staggering occurs as employees tend to start for work earlier and leave later in an attempt to avoid peak congestion. The combined effects of schedule change and relief of congestion on heavily traveled routes can, and probably will, bring about a change in this practice both by the people whose schedules are changed and by the others who will also benefit from improved street conditions. The extent of such changes, however, cannot be easily estimated. Potential changes in behavior make it exceedingly difficult to conclude definitively whether any given work staggering plan will relieve congestion, and if so, to what degree.

An additional problem is that the relieved congestion will probably encourage some increased motor vehicle use for work trips. With

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(continued from page 7-17)
relief -- estimating that a reduction in travel time of 10 minutes per motorist per work hour could be saved. On a 15-minute increment basis, it was estimated that the plan would reduce peak traffic volumes at the cordon about 5 percent in the morning peak and almost 6 percent in the afternoon peak. See Wilbur Smith and Associates, Staggered Hours Plan, Atlanta Metropolitan Area, prepared for the State Highway Department of Georgia et al. (Columbia, South Carolina: Wilbur Smith and Associates, 1970).

improved travel conditions resulting from staggering, some people now using other modes (subways, buses, taxis) may shift to commuting by private passenger car. Compounding the problem even further is the possibility that staggering may also dictate a different temporal distribution of non-work trips. Finally, there is the unknown degree to which work staggering would disrupt car pools. Certainly, rearrangements in work schedules will result in some portion of car pools being disbanded. One study shows that approximately 58 percent of carpoolers in Atlanta said that they would begin to drive alone if this occurred (17 percent said they would take transit and 25 percent were undecided).[1]

To conclude, work staggering could conceivably contribute to relieving peak hour congestion (and reducing motor vehicle emissions, both by increasing average vehicle speeds and by distributing emissions more evenly over time). However, definite conclusions are difficult to draw at this time about the precise impact of work staggering in relieving congestion and resulting emissions more evenly over time.

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[1] See Wilbur Smith and Associates, Staggered Hours Plan, Atlanta Metropolitan Area, prepared for the State Highway Department of Georgia et al. (Columbia, South Carolina: Wilbur Smith and Associates, 1970).

The 4-Day Work Week

A great variety of 4-day work week arrangements are possible. Depending on the arrangement used (or more precisely the combination of arrangements in any metropolitan area), transportation and air pollution impacts can vary considerably. The most common 4-day work week schedule is one in which the firm remains in operation five days a week with only four-fifths of the employees present on a given day. Alternatively, if one-half the employees work Monday through Thursday, and the other half Tuesday through Friday, the entire reductions in journey to work travel would occur on Monday and Friday, when only 50 percent of employees would be reporting for work.[3] Table 7-2 summarizes

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[1] Journey to work trips in a motor vehicle account for slightly less than 30 percent of total motor vehicle trips in the Los Angeles region, 26 percent in the San Francisco area and 15 percent in the Tri State (greater New York) region.

[2] Since less than 1 percent of the labor force is currently on a 4-day work schedule, the assumption that one quarter of employees could be converted within 5 years appears highly optimistic. It is highly unlikely that more than a quarter of the labor force will be on the 4-day week in the next five years.

[3] Reductions in work trips would be realized only if the "extra" day were used for leisure or other non-work purposes. However, it is conceivable that some proportion of the labor force would use the fifth day for "overtime" or part-time employment. The prevalence of such activity will determine the extent to which the actual reduction in journey to work travel approaches the 20 percent (i.e., two less work trips per week) reduction possibility.

a number of possible 4-day working arrangements and indicates the percentage of employees who would be reporting for work on each of the days of the week under the particular arrangement.

Table 7-2

POSSIBLE ARRANGEMENTS OF A 4-DAY WORK WEEK

4-Day Employee Weekly Work Schedule	Percent of Employees on 4-Day Working a Given Day					
	M	Tu	W	Th	F	S
1. Equally rotated M-F	80	80	80	80	80	-
2. 1/2 M-Th; 1/2 Tu-F	50	100	100	100	50	-
3. Equally rotated M-Sa.	67	67	67	67	67	67
4. 1/3 M-Th; 1/3 Tu-F; 1/3 W-Sa	33	67	100	100	67	33
5. 1/2 M-Th; 1/2 W-Sa	50	50	100	100	50	50

Source: Vincent R. Desimone, "The 4 Day Work Week and Transportation", A paper presented to the Joint ASCE ASME Transportation Engineering Meeting, Seattle, Washington; July 1971, p.9.

As Table 7-2 indicates, the 4-day week has the potential for affording significant peak hours congestion relief, at least on some working days. The degree of refief on a given day, of course, varies with the percent of employees working. As the percent diminishes, there will almost always be a reduction in the number of quarter-hour periods where roadway demand exceeds capacity.

In an attempt to quantify these reductions, a recent study was made of the impact of the 4-day week on Los Angeles freeway travel during the peak periods. The findings of this study concerning daily and weekly transportation impact are summarized in Tables 7-3 and 7-4.

Table 7-3

DAILY IMPACT OF 4-DAY WORK WEEK ON CONDITIONS[1]
AT A FREEWAY BOTTLENECK

Percent of 4-Day Employees Working	Number of 15 Minute Periods Demand Exceeds Capacity	Excess Demand Over Capacity (Vehicles)	Reduction from Current Conditions[2] (%)
100	8	1,181	33
80	3	577	69
67	2	414	77
50	2	234	87
33	1	69	99

Source: Adapted from Vincent R. Desimone, "The 4-Day Work Week and Transportation", A paper presented to the Joint ASCE-ASME Transportation Engineering Meeting, Seattle, Washington; July 1971, p.13.

Note: Data assume 35% of the work force is on the 4-day work week.

1. Los Angeles' Hollywood Freeway at Highland Avenue.

2. Under the current 5-day work schedule, the number of 15 minute periods demand exceeds capacity is 12 and the number of vehicles excess demand over capacity is 1815 for a given day.

Table 7-4

WEEKLY IMPACT OF 4-DAY WORK WEEK ON CONDITIONS[1] AT A FREEWAY BOTTLENECK

	Weekly Work Schedule Percent Working on Day Shown						15 Minute Periods Demand Exceeds Capacity	Excess Demand Over Capacity (Vehicles)	Reduction From Current Conditions[2] (%)
	M	T	W	T	F	S			
1.	80	80	80	80	80	0	15	2885	68
2.	50	100	100	100	50	0	28	4011	56
3.	67	67	67	67	67	67	12	2484	73
4.	33	67	100	100	67	33	22	3328	63
5.	50	50	100	100	50	50	24	3298	64

Source: Adapted from Vincent R. Desimone, "The 4-Day Work Week amd Transportation", A paper presented to the Joint ASCE ASME Transportation Engineering Meeting, Seattle, Washington, July 1971, p.13.

Note: Data assume 35 percent of the work force is on the 4-day work week.

[1] Los Angeles' Hollywood Freeway at Highland Avenue.

[2] Under the current 5-day work schedule the number of 15-minute periods demand exceeds capacity is 60 and the number of vehicles excess demand over capacity is 9075 for an entire week.

Table 7-3 shows that reductions in demand over capacity can range from a low of 33 percent at 100 percent of 4-day employees working to 99 percent at 33 percent of 4-day employees working. It is interesting to note that at 100 percent of 4-day employees working, the one-third reduction over current conditions occurs even though the same number of vehicles are traveling during a day. The reason for this is a spreading of the peak which occurs because 4-day employees generally start work earlier than those on the 5-day week, an effect indentical to the staggering of work hours. As Table 7-4 indicates, the particular 4-day work schedule employed can have significant impact on reducing the excess of demand over capacity -- varying from 73 percent reduction under schedule 3 (i.e., and equally rotated 6-day schedule) to 56 percent under schedule 2 (i.e., one half working Monday through Thursday and one half Tuesday through Friday). Perhaps the clearest way of summarizing this information and illustrating the potential of the 4-day week to more effectively utilize existing roadway capacity would be to plot daily roadway demand under various levels of 4-day employees reporting for work versus time. This graph is depicted in Figure 7-2.

Figure 7-3 indicates the potential of a 4-day week to alleviate the frequency[1] and duration of congestion during peak hours. The extent to which this potential can be realized (and air quality improvements result) depends upon a host of factors (e.g., diversion out of mass transit and car-pools to the automobile because of improved travel times, increased overlap of non-work trips during the peak hours, and

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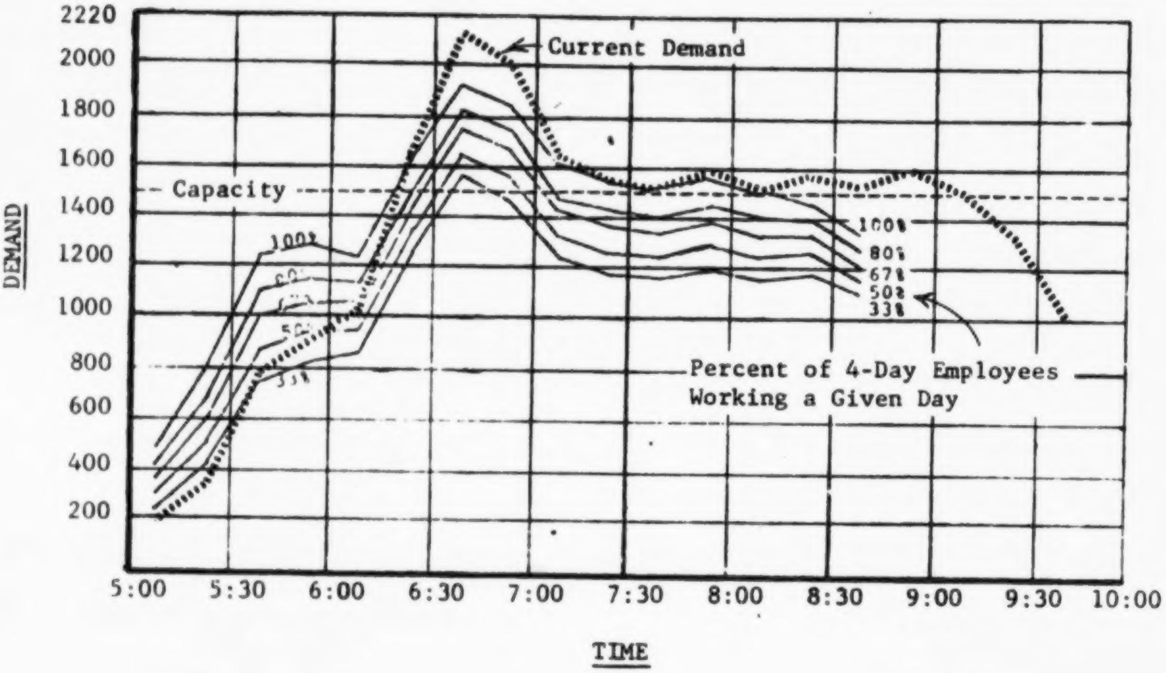
1. That is, the number of times that demand exceeds capacity.

Figure 7-3

DAILY DEMAND ON L.A. FREEWAY SYSTEM OVER TIME[1]
UNDER SEVERAL 4-DAY WORK WEEK SCHEDULES



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[1] Los Angeles' Hollywood Freeway at Highland Avenue.

Source: Adapted from Vincent R. Desimone, "The 4-Day Work Week and Transportation," a paper presented to the Joint ASCE-ASME Transportation Engineering Meeting, Seattle, Washington, July 1971, p. 14. Data assume 35 percent of the work force is on the 4-day work week.

so forth[1]). Hence, it is not possible to estimate with certainty emission reductions which would result.[2]

If the 4-day week is to be an effective short-term control, a "substantial" portion of the labor force in any metropolitan area would have to be converted to new schedules within five years. "Substantial," however, need not imply that in order to effect important emission reductions, the proportion of the work force on the 4-day week must approach 100 percent. In fact, constructing a table similar to Table 7-4 but with 100 percent of all employees on the 4-day week, indicates that mobility is actually better if 35 percent of all employees are on the 4-day week than if 100 percent are.[3] This is due to the spreading of the peak that occurs when portions of the labor force have different hours than others.

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[1] Over a longer period, several other considerations should be weighed in evaluating the air pollution control potential of the 4-day week. Most significantly, it is likely that decreased travel time will encourage auto commuters to live even farther from work, thus increasing dispersion. Further, commuting fewer days could conceivably increase the tolerance for driving with a resultant reduction in mass transit ridership (although it is also possible that longer days would lessen tolerable levels for driving in congested areas).

[2] The distinction between reductions in peak hour travel and reduction in total travel should be noted. Although the 4-day week appears to have significant potential to reduce peak hour travel, it probably will not reduce total travel and may actually increase it. There is no doubt that additional motor vehicle travel would be generated during the longer contiguous periods of non-work afforded by the 4-day week. However, most of this travel will be for pleasure or vacation, visiting relatives, and so forth. Consequently, such travel is likely to be during predominantly non-peak hours. What is more, the travel may well occur primarily outside the CBD, in large measure, on rural and recreational roads. Thus, from the standpoint of air pollution control, the shift in time, place, and purpose of travel resulting from the 4-day work week appears beneficial, even if total travel increases somewhat.

[3] Vincent R. Desimone, "The 4-Day Work Week and Transportation." A paper presented to the Joint ASCE-ASME Transportation Engineering Meeting, Seattle, Washington; July 1971, p. 17.

As will be indicated, however (see "Institutional Feasibility"), the number of firms having converted to the 4-day work week at this time is small. However, the rate of conversions has increased substantially in the past year. Thus, although one source has projected 1990 as the earliest time 35 percent of the labor force would be on the 4-day week,[1] this estimate may be unduly low in light of the accelerating rate of conversion.[2]

Maximum Feasible Emission Reduction

For reasons indicated earlier, the 4-day work week holds out more promise for reducing emissions than any work staggering program.

As Table 7-4 indicates, several 4-day work arrangements are possible, each associated with a different percentage of employees reporting for work on a particular day. Thus, although the total weekly vehicle miles traveled for the journey to work would be reduced by 20 percent, daily reduction can vary from no reductions at all to 67 percent. Since the focus of this project is on reducing average 8-hour carbon monoxide concentrations, it is the daily reduction in vehicle miles traveled that is significant, rather than weekly totals.

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[1] William W. Nash, Jr., Implications for Urban America, cited in Vincent R. Desimone, "The 4-Day Work Week and Transportation," A paper presented to the Joint ASCE-ASME Transportation Engineering Meeting, Seattle, Washington; July 1971, p. 7.

[2] In discussing the rate of conversions to the 4-day week, it should be borne in mind that the complete transition to the present 5-day week (from six) took place in about 20 years. In 1918, there were only a few 5-day firms; some 11 years later only 5 percent of the labor force was on 5-day; and by 1940 the 5-day week was the established norm.

It should also be noted that recently effective federal legislation has shifted a number of holidays to Monday. This has resulted in ten 4-day weeks in 1971, which means about one-fifth of the year is already made up of 4-day weeks.

Accordingly, 4-day work arrangements that result in no reduction in the percentage of employees reporting for work on any weekday are less acceptable for air pollution control purposes (even if considerable reductions occur on all other days of the week) than equally rotated 4-day work schedules (see Table 7-4). With an equally rotated Monday to Friday arrangement, work trips (of the 4-day labor force) on each day would be reduced by 20 percent, while an equally rotated Monday to Saturday arrangement would result in a daily reduction of work trips by 33 percent. On this basis it can be concluded that an equally rotated Monday to Saturday schedule (i.e., the 4-day week spread over six days) is the arrangement which would result in the most emission reductions.

Since only a third of the 4-day week labor force does not report for work on any working day under this arrangement, the reductions in vehicle miles traveled (and hence emissions attributable to reduced travel[1]) can be readily calculated. Assuming that approximately 30 percent of vehicle miles traveled are attributable to work trips,[2] and that a maximum of 25 percent of the labor force would be on the 4-day week by 1977,[3] the maximum daily reductions in vehicle miles traveled from the 4-day work week can be estimated at 2.5 percent (.33 x .30 x .25).

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1. In addition to reduced travel, emission reductions would probably result from improved flows. Calculation of these "additive" effects, however, cannot be carried out without computer simulation and extensive analysis of demand and capacity relationship on a city-by-city basis. For several illustrative examples of these relationships, see Appendix C.

2. Journey-to-work trips in motor vehicles account for slightly less than 30 percent of total motor vehicles trips in the Los Angeles region, 26 percent in the San Francisco area and 15 percent in the Tri-State (greater New York) region.

3. Since less than 1 percent of the labor force is currently on a 4-day work schedule, the assumption that this figure will increase to 25 percent within five years would appear highly optimistic.

Institutional Feasibility

As earlier indicated ("Definition of Terms"), work schedule change possibilities may be grouped into two categories, "Work Staggering" and "The 4-day Week." Most variants of work staggering entail relatively minor modifications in economic activity, travel patterns, and overall life styles. The 4-day work week, on the other hand, implies a profound alteration in productivity, work, habits, recreational patterns, leisure time, and so forth. These profound implications of any large shift to the 4-day working week would seem to preclude the possibility of its being introduced merely to reduce motor vehicle congestion and emissions. Any evaluation of the feasibility (and desirability of the 4-day work week) should consider this wide range of impacts; and the air pollution control potential of such a policy, of course, should be borne in mind as it is being evaluated.[1] It should be noted, nevertheless, that the 4-day work week appears to be gaining popularity in the United States (although at present only a small fraction of the labor force works under this schedule).[2]

We confine the following, therefore, to a discussion of work staggering. It should be borne in mind that considerations of feasibility vary somewhat from city to city depending on factors including the location and kinds of employment centers, location and kinds of employment, residential patterns, the existing transportation system (e.g., roadways, rapid rail lines) and so forth.

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[1] Attention should also be paid to the safety aspects of the 4-day week. Present patterns indicate that the 4-day week has a high potential for increasing accidents and accident rates. Current injury accident rates are about 30 percent higher on week-ends than on weekdays with rates on 3-day weekends about the same as 2-day weekends. A mid-week holiday, on the other hand, seems to produce about an 80 percent increase over the weekday rates.

[2] Growing interest in the 4-day work week is reflected in a recently initiated newsletter on the subject. According to a recent issue, the rate of conversion to reduced work weeks, reported in mid-1970 to be two firms a day, had doubled in less than a year. Poor's Workweek Letter, (Cambridge, Mass.: September 1, 1971), p. 1.

Staggering Work Hours

Work hour staggering is by no means new, having been initiated in cities both in the United States and abroad as early as the 1920's.[1] At the present time there are two recently initiated work-hour staggering projects in existence: in the lower Manhattan area of New York City and in Washington, D.C. In addition, a work hour staggering study has been recently completed for the City of Atlanta.[2]

In order for work staggering to be feasible, sufficient[3] unused roadway capacity must exist before and/or after peak traffic periods. If demand already exceeds capacity over relatively long periods, little relief of roadway congestion can result from staggering work hours. However, since capacity in and around the CBD's of most cities is generally expanded with the goal of adequately meeting peak hour demand, "sufficient" unused or available capacity exists in most cities before and after the peak.

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[1] During World War II, considerable attention was focused on work staggering and actual plans were implemented in some 60 American cities to alleviate transportation problems. (The most extensive experience with work-hour staggering has occurred in Washington, D.C. where a program was introduced in World War II and again in the 1960's.) Unfortunately, however, there was virtually no evaluation of these World War II experiences (all of which were terminated after the war). As one comprehensive study of work-hour staggering points out about the World War II work staggering experience, "Perhaps its most persistent theme is the absence of a record of results." Lawrence B. Cohen, Work Staggering for Traffic Relief: An Analysis of Manhattan's Central Business District (New York: Praeger, 1968) p. 6.

[2] Wilbur Smith and Associates, Staggered Hours Plan Atlanta Metropolitan Area (Columbia, South Carolina: 1970.

[3] That is, sufficient to accommodate large enough portions of peak traffic to produce a significant improvement in traffic conditions.

Feasibility also implies that work staggering plans be clear and simple, and hence readily comprehensible to all concerned. Plans consisting of separate and detailed schedules for individual firms would be exceedingly difficult to implement. In addition, for most work hour staggering programs to be feasible, participation must be on a voluntary basis, both for the employer and the employee. This does not mean that every individual employee be free to accept or reject work staggering, but simply that collectively employees would voluntarily comply. As one comprehensive work staggering study states:

> This stricture of a voluntary program is in one sense simply a recognition of social reality. There simply is no way by which work staggering could be forcefully imposed upon the community...[1]

Above all, for work staggering to be feasible -- indeed to occur at all -- work schedules must be subject to modification. Employers and employees in other words, must be able to accommodate work schedule changes. Most employers, for example, will wish to consider the impact of work schedule changes on the economic viability of their enterprise, while employees will consider the potential of modified work schedules to disrupt their daily patterns.

Feasibility for employers. The need to maintain specified work schedules differs from firm to firm. If a firm's schedule differs from that of its suppliers and/or customers, economic activity is precluded during portions of the day. Depending on how essential are these activities, schedule changes (whether of the firm, its suppliers, or customers) may cause losses in sales, failure to receive or deliver merchandise, supplies or services, and so forth. Schedule changes could also cause inefficiencies within a given firm.

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[1] Lawrence B. Cohen, Work Staggering for Traffic Relief: An Analysis of Manhattan's Central Business District (New York: Praeger, 1968), p. 9.

Detailed industry studies conducted for the Manhattan and Atlanta CBD's provide many insights into these economic interrelationships and the potential impact of work-hour scheduling on efficient conduct of business.[1] Based on observations of industry-wide business practices it was possible to determine which industries had work schedules which were most subject to modification. Furthermore, it was found that the extent to which modifications were possible could be detailed for specific industry classifications. In general, trade oriented firms (i.e., firms such as retail shoes or wholesale establishments that must adjust their hours to customer flow and must be located where and when customers are present) were found to have schedules which must conform to those of others. Such firms could only shift if their customers shift.

Other firms were found which had to adapt their working hours to industry requirements or outside factors (e.g., flow of materials, arrival of intercity carriers) or the hours observed by the home office in another city (e.g., stock brokerage firms, firms accessing a central computer). In general, such firms have relatively fixed working hours. Transportation, communication, and utilities, since they cater to customers as well as out-of-town affiliates, are examples of industries falling in this classification.

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[1] Industry surveys and sociological analyses for Manhattan were conducted as part of comprehensive research on work hour staggering. These studies were independently released but are adequately summarized in the previously noted work. Lawrence B. Cohen, Work Staggering for Traffic Relief: An Analysis of Manhattan's Central Business District, (New York: Praeger, 1968), Chapters 4 and 5.

A considerable number of firms, not bound by customer flow or other external factors, have great latitude in scheduling working hours. These firms, of course, form the target in the design of a staggered hours program. Organizations primarily administrative in nature -- especially governmental agencies -- mainly comprise this category. Table 7-5 summarizes the schedule freedom and, thus, the staggered hours potential for a variety of employment classifications in the Atlanta CBD.

Both the Manhattan and Atlanta studies concluded that latitude for schedule change varies among firms and industries, but that the notion of all firms or industries having fixed schedules and not being able to conduct their operations otherwise could not be supported.

Feasibility for employees. As indicated above, work staggering must also be acceptable to the employees (and others) involved. Quite obviously changes in work schedule may have significant repercussions in well-established social and cultural patterns to which employees have become accustomed. Work schedule changes may entail modifications in departure times to and from work, the portions of the day spent home, and the hours spent in social, recreational or other activities. These changes, in turn, could affect employee's families, friends, and associates as well as the schedules of the businesses, services, and institutions with which they deal. Given these potential consequences from changing work hour schedules, the extent to which work schedule changes are sufficiently acceptable for those affected must be determined.

Table 7-5

SUMMARY OF SCHEDULE FREEDOM AND STAGGERED HOURS POTENTIAL BY EMPLOYMENT CLASSIFICATION

Employment Classification	Schedule Freedom	Staggered Hours Potential
Federal Government	Free[1]	Good; many small agencies
State Government	Free	Good
Local Government	Free	Good
Trans-Comm-Util.	Fixed[2]	Poor; transportation (trade oriented)
Education	Fixed	Poor
Service	Free	Good; banks (trade oriented)
Retail	Flexible[3]	Fair; large firms only
Manufacturing	Free	Fair +
Wholesale	Flexible	Poor

Source: Adapted from Wilbur Smith and Associates, "Staggered Hours Plan, Atlanta Metropolitan Area," 1970, p. 31

1. "Free" indicates organizations with considerable latitude to set work hour schedules. In theory, schedules could encompass any period in the day if it were not for employee preferences. Shifts of at least one to two hours appear possible.

2. "Fixed" indicates organizations with no flexibility to change work patterns to any schedule other than existing ones.

3. "Flexible" indicates organizations which could potentially alter work hour schedules, but only if related firms (i.e., firms in the industry, customers, suppliers, and so forth) do the same. Since such shifts from established economic relationships usually involve a great number of firms and business practices, the extent of schedule change acceptable to such organizations is probably one hour or less.

Seeking to resolve this issue, a team of sociologists conducted a large-scale survey of employee attitudes toward work staggering in the Manhattan CBD. Among other things, employees were asked when they would prefer to start and stop work (assuming they had free choice and the same number of working hours were required as the present). The survey results are shown in Table 7-6.

Table 7-6

PERCENTS OF SAMPLE PREFERRING CHANGED STARTING TIMES, BY MINUTES OF CHANGE[1]

Minutes of Change		Percent Earlier	Percent Later
15 - 29		10	6
30 - 59		21	9
60 or more		12	6
	Total	43	21

Source: Lawrence B. Cohen, Work Staggering for Traffic Relief: An Analysis of Manhattan's Central Business District (New York: Praeger, 1966), p. 190

As indicated, only 37 percent stated a preference for present starting times, with some 64 percent (rounding discrepancies) preferring times other than those they now have. This result may seem surprising since most employees appear satisfied with their present schedules, at least judging from the absence of union (or other employee) pressure in this regard. In an attempt to explain this finding, the authors of the Manhattan work staggering study conclude:

> . . . while most respondents reported being satisfied with their work times, . . . most also preferred different work times. The reason is now clear: work times compared with other aspects of a job or with other times in a person's schedule are just not very important to the respondents. They are not psychologically salient elements nor are they something that most people care very deeply about. Hence they are 'satisfied' with them -- why not? -- but at the same time they prefer other ones.[1]

In addition to preference, the Manhattan study sought to determine the "tolerance level" of employees to schedule change. Tolerance was defined as the extent of change respondents were willing "to go along with behaviorly", i.e., the boundary of non-resistance. As might be expected, the results indicate that people tolerate far more change than they prefer: an earlier starting time would be preferred by 43 percent of the people, while 93 percent will tolerate an earlier starting time. A later starting time would be preferred by 21 percent of the people, and tolerated by 86 percent. On the basis of this, and other evidence, the study concluded that "there are some who object to schedule change, but they are too few and too scattered to be considered a source of effective resistance."

The finding of this a priori study that work hour staggering would be feasible -- both for employers and employees -- appear confirmed by the experience of two on-going work-hour staggering projects. In the lower Manhattan project, sponsored by the Port of New York Authority and the

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[1] Lawrence B. Cohen, Work Staggering for Traffic Relief: An Analysis of Manhattan's Central Business District (New York: Praeger, 1968), p. 191.

Downtown-Lower Manhattan Association, approximately 50,000 persons employed by 45 firms and government agencies in lower Manhattan began shifting work hours (principally off the 9-5 schedule to 8:30 AM to 4:30 PM) in April 1970. As of one year later, there were about 60,000 perople representing 70 private firms and government agencies on the new schedule. The results of a recently released evaluation of this project indicate conclusively that both regular employees and their supervisors viewed their personal experiences in positive terms under staggered work hours contributed to enhanced efficiency in their organizations.

In brief, some of the most significant findings of the Lower Manhattan Association hour staggering program were: (1) almost 85 percent of the participants were more satisfied with commuting under the staggered schedule, while only 10 percent were less satisfied; (3) almost all project participants highly favored the project in terms of its effects on home life, their evening activities, and so forth; and (4) more than 21 percent of the participants reported increased work effectiveness (while only 4 percent reported a decrease in work effectiveness). The report containing these findings concluded:

> from the enthusiastic reactions of the participants in both government and industry, . . . the project can be termed an unqualified success. We learned, in the first year, that thousands of men and women who work in lower Manhattan are quite willing to change their work schedule in order to make traveling more comfortable. We learned further that the shift did not have a detrimental effect on the operations or efficiency of the firms participating; indeed, in most cases, the effects on efficiency were positive. These were the two key questions the porject sponsors set out to research. They have been answered affirmatively.[1]

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[1] Downtown-Lower Manhattan Association and the Port of New York Authority, Staggered Work Hours in Lower Manhattan, First Anniversary Report, April 1971, p. 2.

Recent (1969-1970) experiences with staggering in the Washington, D.C., metropolitan area have also indicated the feasibility of work hour staggering. In the most recent experience, a staggered work hour plan was implemented for 24 federal agencies employing over 18,000 employees in Crystal City, Virginia. The schedule shifts -- which started work earlier in amounts up to one hour -- engendered only "minor and informal complaints" according to a follow-up study.[1]

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[1] Chester Roy Julian, "Staggering Work Hours to Ease Existing Street Capacity Problems," a paper prepared for the 1970 World Traffic Engineering Conference; Montreal, Canada (September 1971), p. 38. The possibility of employer resistance did not arise for federal agencies in the Washington area as it might for private sector employers elsewhere.

APPENDICES

APPENDIX A

ESTIMATING EMISSION REDUCTIONS FROM RETROFIT[1]

Estimating the emission reductions from retrofit requires consideration of: (1) the contribution of pre-controlled vehicles to aggregate (i.e., light duty motor) vehicle miles traveled (taking into account that pre controlled vehicles are fewer in number but tend to be driven less than newer ones); and (2) the emissions from an average pre-controlled vehicle compared with those from a controlled vehicle. With these data, the aggregate emission reduction following retrofit installation can be computed by multiplying the expected per vehicle emission reduction following retrofit installation by the ratio of pre-controlled automobile emissions to total automobile emissions in a given year. The basic working equation is as follows:

$$\text{Percent initial reduction in aggregate emissions due to retrofit installation in year N} = \left[\text{Maximum expected emission reduction for average pre-controlled vehicle fitted with retrofit device (estimated in this report to be 25 percent)}\right]\left[\frac{\text{Total emissions from pre-controlled automobiles in year N}}{\text{Total emissions from all automobiles in year N}}\right]$$

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[1] All estimates are for initial reductions, and do not take into account deterioration of retrofit devices due to accumulation of mileage. By "emissions" we refer to carbon monoxide; by "aggregate" emissions (or emission reductions) we mean the carbon monoxide attributable to light duty motor vehicles in any given area. Thus, to the extent that emissions are attributable to heavy duty vehicles (e.g., buses, trucks) or to stationary sources (e.g., space heating), reductions in overall emissions (i.e., carbon monoxide from all sources in a given area) will be less than estimated here.

Expressing the above equation symbolically, we have

$$(1) \qquad \Delta E_N = R \times \left[\frac{\sum_{i=N-12}^{M} (VMT_i \times EF_i)}{\sum_{i=N-12}^{N} (VMT_i \times EF_i)} \right]$$

Note: The subscript "N-12" reflects the fact that, based on existing trends, the preponderance (over 97%) of vehicle miles traveled will be generated in year N (1975 or 1977) by vehicles 12 years old or newer.

ΔE_N	is the initial reduction in emissions following retrofit installation in year N, expressed as a percentage of aggregate emissions;
R	is the maximum expected emission reduction for an average pre-controlled vehicle fitted with retrofit device (estimated in this report to be 25 percent);
M	is the last pre-controlled model year (1965 for California vehicles, 1967 for all others);
VMT_i	is the total annual vehicles miles traveled by vehicles of model year i;
EF_i	is the average per-mile emission factor for vehicles of model year i.

The potential aggregate emission reduction from retrofit installation can be projected for any future year by inserting the appropriate vehicle miles traveled and emission data as indicated above. For example, the aggregate emission reduction in 1975 resulting from retrofit installation on pre-controlled vehicles in California can be calculated on the basis of the data shown in the table below. In this table, VMT values are expressed relative to the base year (in this case 1975) and do not correspond to any particular model year. EF values, in contrast, relate to the particular model year.

Model Year i	VMT_i[1]	EF_i[2]
1975	16%	55 g/mile
1974	14	61
1973	12	66
1972	10	71
1971	9	78
1970	8	84
1969	8	91
1968	7	96
1967	5	101
1966	4	106
1965	3	112
1964	2	112
1963	3	112

1. T. A. Bostich and H. J. Greehalgh, "Relationship of Passenger Car Age and Other Factors to Miles Driven" (Washington, D.C.: U. S. Department of Commerce, Bureau of Public Roads, January 1967), as cited in H. W. Sigworth, Jr., "Estimates of Motor Vehicle Emission Rates" (unpublished paper prepared for the U.S. Environmental Protection Agency, Washington, D.C., March 15, 1971), p. 14.

2. H. W. Sigworth, Jr., "Estimates of Motor Vehicle Emission Rates" (unpublished paper prepared for the U.S. Environmental Protection Agency, Washington, D.C., March 15, 1971), p. 13.

The future per-mile emission factors are, of course, speculative. As indicated elsewhere, there is some uncertainty also about actual on-the-road emission factors for present in-use vehicles. The specific set of factors used in the above analysis appear to be as representative as any other. However, even if the emission factors used for controlled vehicles were lower by 10 or 15 percent (as some research has indicated), the effect on potential aggregate emission reductions following retrofit would be negligible. For example, in the calculations for California, reducing the emission factors of controlled vehicles by 10 percent increases the aggregate emission reduction potential of retrofit by less than 0.5 percent.

Inserting these numbers into equation (1) above yields an expected aggregate emission reduction of 2.9 percent in 1975:

$$(2) \quad \Delta E_{1975} = .25 \left[\frac{(3x112)+(2x112)+(3x112)}{\begin{array}{c}(3x112)+(2x112)+(3x112)\\ +(4x106)+(5x101)+(7x96)+(8x91)+(8x84)\\ +(9x78)+(10x71)+(12x66)+(14x61)+(16x55)\end{array}} \right]$$

$$= .25 \left[\frac{896}{7835} \right] = .02859$$

$$= 2.9\%$$

APPENDIX B

ESTIMATING EMISSION REDUCTIONS FROM CONVERSION TO GASEOUS FUELS[1]

Conversion of New York City Medallion Taxicabs

For reasons indicated in Chapter 2, we have chosen New York City's medallion taxis to illustrate the maximum feasible emission reduction from conversion to gaseous fuels. The calculations in this Appendix represent control beyond that which is expected to occur as a result of normal vehicle turnover rates and full compliance with federal new car standards.[2] The computations require consideration of (1) pre- and post-conversion emission factors; (2) the emissions from medallion taxis in the area considered; and (3) the total and aggregate motor vehicle emissions in the specified area.[3] Basic data for these calculations are presented in Table B-1.

---

[1] Unless otherwise indicated, the computations in this Appendix are based on data from the New York Environmental Protection Administration "Proposed Plan for Meeting Federal Air Quality Standards Relating to Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, and Oxidants in New York City," New York, 1972. (Mimeographed draft.)

[2] In addition, all estimates are for initial reductions and do not take into account deterioration due to accumulation of mileage. By "emissions" we refer to carbon monoxide; by "aggregate" we mean emissions or emission reductions attributable to light duty motor vehicles; by "total" we refer to emissions or emission reductions attributable to all motor vehicles (i.e., both light and heavy duty). Finally, "overall" emissions refer to carbon monoxide from all mobile and stationary sources in any given area.

[3] Motor vehicles account for 97 percent of carbon monoxide emissions in New York City in 1970 and a projected 98 percent in 1975.

Table B-1

BASIC NEW YORK CITY DATA FOR 1975[1]

Carbon Monoxide Emission Factors	
Manhattan Fleet Medallion Taxicabs	33.9 grams/mile
Manhattan Non-fleet Medallion Taxicabs	53.1 grams/mile
Percentage of Overall CO Emissions in New York City Attributable to Motor Vehicles	
1970	97%
1975	98%
Borough of Manhattan	
Total CO Emissions from Motor Vehicles	221,471 tons/year
Aggregate CO Emissions from Light Duty Vehicles	148,574 tons/year
CO Emissions from Fleet Medallion Taxicabs	14,124 tons/year
CO Emissions from Non-Fleet Medallion Taxicabs	8,100 tons/year
Midtown Manhattan Central Business District	
Total CO Emissions from Motor Vehicles	56,771 tons/year
Aggregate CO Emissions from Light Duty Vehicles	26,170 tons/year
CO Emissions from Fleet Medallion Taxicabs	10,187 tons/year
CO Emissions from Non-Fleet Medallion Taxicabs	7,366 tons/year

Source: New York Environmental Protection Administration, "Proposed Plan for Meeting Federal Air Quality Standards Relating to Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, and Oxidants in New York City," New York, 1972. (Mimeographed draft.)

1. Full compliance with federal new car emission standards and normal vehicle turnover rates are assumed.

Emission Reduction for Fleet and Non-fleet Medallion Taxicab Populations

In order to demonstrate the sensitivity of overall emission reduction projections to the estimated emission reduction for specific converted taxicab populations, two different reported values will be used in this analysis: a 60 percent reduction in CO emissions from fleet and non-fleet medallion taxicabs;[1] and a carbon monoxide emission factor of 5 grams/mile for all converted vehicles.[2] The latter is equivalent to the following emission reductions for specific taxicab populations in Manhattan:

$$\text{Emission reduction for specific vehicle population} = \frac{\text{overall emission factor for specified vehicle population, g/mile} - (5.0\ \text{grams/mile})}{\text{overall emission factor for vehicle population, g/mile}} \times 100\%$$

$$\text{Emission reduction for } \underline{\text{fleet medallion vehicles}} = \frac{33.9 - 5.0}{33.9} \times 100\ \%$$

$$= 85.3\%$$

$$\text{Emission reduction for } \underline{\text{non-fleet medallion vehicles}} = \frac{53.1 - 5.0}{53.1} \times 100\%$$

$$= 90.6\%$$

---

[1] New York Environmental Protection Administration, "Proposed Plan for Meeting Federal Air Quality Standards Relating to Carbon Monoxide, Hydrocarbons, Nitrogen Oxides, and Oxidants in New York City," New York, 1972, p. 4-27. (Mimeographed draft.)

Note: The New York City Implementation Plan considered conversion of fleet medallion taxicabs only and therefore the 60 percent assumed reduction in per vehicle carbon monoxide emissions is strictly applicable only to fleet vehicles. However, due to lack of specific N.Y.C. data on emission reductions for non-fleet taxicabs, the 60 percent reduction is assumed to be applicable to both fleet and non-fleet vehicles for the purposes of this calculation.

[2] [see following page]

Reduction in Total CO Emissions from Motor Vehicles

In order to determine the percent reduction in total motor vehicle emissions, the emission reduction achievable through conversion of medallion taxicabs must be weighted by the relative contribution of these vehicles to the total motor vehicle emissions in the geographical area under consideration.[1] The general relationship is:

$$\Delta E = \begin{array}{l}\text{Reduction in total}\\ \text{CO emissions from}\\ \text{motor vehicles}\end{array} = \frac{\left[\begin{array}{l}\text{Emissions reduction}\\ \text{for vehicle population}\\ \text{under consideration, e.g.,}\\ \text{fleet or non-fleet}\end{array}\right]\left[\begin{array}{l}\text{Total CO emissions}\\ \text{from vehicle population}\\ \text{under consideration in the}\\ \text{specified geographical area}\end{array}\right]}{\left[\begin{array}{l}\text{Total CO emissions from all}\\ \text{motor vehicles in the speci-}\\ \text{fied geographical area}\end{array}\right]} \times 100\%$$

(continued from previous page)

2. Estimated on the basis of simple conversion involving the installation of gaseous fuel system, pressure regulator, air-gas mixer, blocked manifold heat, and some minor adjustments of engine variables -- such as a leaner air fuel ratio, slightly retarded timing, increased idle speed, and disconnected vacuum advance. Source: Institute of Gas Technology, Emission Reduction Using Gaseous Fuels for Vehicular Propulsion (Chicago: Institute of Gas Technology, 1971), p. 3-11.

Note: This is basically an "initial" emission factor representing emissions from newly converted vehicles and does not account for the possibility of deterioration in control efficiency (i.e., an increasing emission factor over time) with accumulated mileage. There appears to be no reliable data on control efficiency deterioration for gaseous fuel vehicles.

[1] In order to obtain aggregate (i.e., light duty motor vehicle) emission reductions, the same procedure would be followed using aggregate emission data from Table B-1.

I. Borough of Manhattan

A. Conversion of all fleet and non-fleet medallion taxicabs in the 1975 Manhattan taxi population -- effect on total carbon monoxide emissions from all motor vehicles in the Borough of Manhattan.

1. Assuming 85.3% reduction in CO emissions for converted fleet vehicles and 90.6% reduction in CO emissions for converted non-fleet vehicles (i.e., using the 5.0 g/mile emission factor for converted vehicles).

$$\Delta E = \frac{(0.853)\left(\begin{array}{l}\text{CO emissions from}\\ \underline{\text{fleet}}\text{ medallion taxi-}\\ \text{cabs in Manhattan,}\\ \text{tons/year}\end{array}\right) + (0.906)\left(\begin{array}{l}\text{CO emissions from}\\ \underline{\text{non-fleet}}\text{ medallion}\\ \text{taxicabs in Manhattan,}\\ \text{tons/year}\end{array}\right)}{\text{Total CO emissions from motor vehicles in Manhattan, tons/year}} \times 100\%$$

$$= \frac{(0.853)\ (14{,}124\text{ tons/year}) + (0.906)\ (8100\text{ tons/year})}{221{,}471\text{ tons/year}} \times 100\%$$

$$= 8.8\%$$

2. Assuming 60% reduction in CO emissions from converted fleet and non-fleet vehicles.

$$\Delta E = \frac{(0.60)\ (14{,}124\text{ tons/year} + 8100\text{ tons/year})}{221{,}471\text{ tons/year}} \times 100\%$$

$$= 6.0\%$$

B. Conversion of all fleet medallion taxicabs in the 1975 Manhattan taxi population -- effect on total carbon monoxide emissions from motor vehicles in the Borough of Manhattan.

1. Assuming 85.3% reduction in CO emissions for converted fleet vehicles and 90.6% reduction in CO emissions for converted non-fleet vehicles.

$$\Delta E = \frac{(0.853)\ (14{,}124 \text{ tons/year})}{221{,}471 \text{ tons/year}} \times 100\%$$

$$= 5.4\%$$

2. Assuming a 60% reduction in CO emissions for converted fleet and non-fleet vehicles.

$$\Delta E = \frac{(0.60)\ (14{,}124)}{221{,}471} \times 100\%$$

$$= 3.8\%$$

II. Midtown Manhattan Central Business District

A. Conversion of all fleet and non-fleet medallion taxicabs in the 1975 Midtown Manhattan Central Business District taxi population -- effect on total carbon monoxide emissions from all motor vehicles in the Midtown Manhattan CBD.

1. Assuming 85.3% reduction in CO emissions for converted fleet vehicles and 90.6% reduction in CO emissions for converted non-fleet vehicles (5.0 g/mile emissions factor for converted vehicles).

$$\Delta E = \frac{(0.853)\left(\begin{array}{l}\text{CO emissions from}\\ \underline{\text{fleet}}\text{ medallion}\\ \text{taxicabs in Midtown}\\ \text{CBD, tons/year}\end{array}\right) + (0.906)\left(\begin{array}{l}\text{CO emissions from}\\ \underline{\text{non-fleet}}\text{ medallion}\\ \text{taxicabs in Midtown}\\ \text{CBD, tons/year}\end{array}\right)}{\text{Total motor vehicle CO emissions in Midtown CBD, tons/year}} \times 100\%$$

$$= \frac{0.853\ (10{,}187) + 0.906\ (7{,}366)}{56{,}771} \times 100\%$$

$$= 27.1\%$$

2. Assuming 60% reduction in CO emissions for converted fleet and non-fleet vehicles.

$$\Delta E = \frac{0.60\ (10{,}187\text{ tons/year} + 7{,}366\text{ tons/year})}{56{,}771\text{ tons/year}} \times 100\%$$

$$= 18.5\%$$

B. Conversion of all fleet medallion taxicabs in the 1975 Midtown Manhattan Central Business District taxi population -- effect on total motor vehicle emissions in the Midtown CBD.

1. Assuming 85.3% reduction in CO emissions for converted fleet vehicles and 90.6% reduction in CO emissions for converted non-fleet vehicles.

$$\Delta E = \frac{0.853\ (10{,}187 \text{ tons/year})}{56{,}771 \text{ tons/year}} \times 100\%$$

$$= 15.3\%$$

2. Assuming 60% reduction in CO emissions for converted fleet and non-fleet vehicles.

$$\Delta E = \frac{0.60\ (10{,}187 \text{ tons/year})}{56{,}771 \text{ tons/year}} \times 100\%$$

$$= 10.8\%$$

APPENDIX C

SPEED-EMISSION RELATIONSHIPS

Many of the transportation controls considered in this report have been advanced on the assumption that motor vehicle exhaust emissions (carbon monoxide) are lower in freely flowing traffic at high average vehicle speeds than in congested stop-and-go conditions. Careful consideration of these measures, however, requires recognition of the numerous assumptions and limitations inherent in speed-emission relationships. Unfortunately, basic research on these relationships has not been readily available. Accordingly, we are reproducing the key technical papers in this Appendix in order to present the best available data and complete background information.

Comparison of Auto Exhaust Emissions from Two Major Cities, Rose, et al. (1964) is the definitive work on the effect of automobile speed on exhaust emissions. In this study, on-the-road samples of exhaust from precontrolled automobiles indicated a consistent relationship of decreasing hydrocarbon and carbon monoxide emissions with increasing average route speed (distance/time). Nitrogen oxide emissions were found to be independent of vehicle speed. It should be emphasized that the speed-emission relationships developed in this document are applicable only to automobiles without exhaust control devices.

Project M-220, Effect of Speed on Emissions (1971), California Air Resources Board, was based on an extremely limited sample of both precontrolled and controlled automobiles. Exhaust emissions were monitored while the vehicles were exercised on a chassis dynamometer at specific steady-state speeds and at average speeds represented by the California 7-mode procedure. It is important to note the distinction between steady-state speeds which do not include idle, acceleration, and deceleration (Figures 1 through 4); and average speeds which represent actual driving patterns including idle, acceleration, and deceleration sequences (Figure 5). This difference is clearly illustrated in Figure 5. The general trend of decreasing hydrocarbon and carbon monoxide emissions with increasing average speed was confirmed in this study (Figure 5). Nitric oxide emissions were found to increase with average speed (Figure 5a).

C-3

Project M-220

EFFECT OF SPEED ON EMISSIONS

March 1971

California Air Resources Board
Air Resources Laboratory
434 South San Pedro Street
Los Angeles, California 90013

Project M-220

EFFECT OF SPEED EMISSIONS

Introduction

The purpose of the tests covered in this report was to determine the effects of vehicle speed on emissions.

Five vehicles were tested. They included:

1971 Chrysler	(383 in^3)
1971 Dart	(318 in^3)
1970 Chevrolet	(350 in^3)
1964 Chevrolet	(283 in^3)
1971 Pontiac	(350 in^3)

All vehicles were tested at a true speed of 20, 30, 40, 50, 60 and 70 miles per hour.

Test Procedure

1. Each vehicle was run on the dynamometer at a steady speed for 2 to 5 minutes (until all readings were reasonably stabilized). Inertia load was set corresponding to vehicle weight and road load was set per 7-mode procedure.

2. Consecutive runs were made at 20, 30, 40, 50, 60 and 70 miles per hour. Road load which had been set at 50 miles per hour was allowed to change with speed per the dynamometer curve (cube function).

3. After conditions had stabilized at each speed, hydrocarbon, carbon monoxide, and nitric oxide were recorded by chart readout of NDIR instruments. Simultaneously the exhaust gas was collected in bags for a timed period of 1 to 3 minutes depending on speed.

4. After each run the exhaust was discharged from the bag and the flow rate and time measured on a chart recorder.

5. Calculations were made to obtain exhaust volume per mile and miles travelled during exhaust gas collection. These values were used to calculate the mass emissions on a grams/mile basis.

Results

Results are shown in Figures 1 to 4. Figures 1. 2. and 3 show hydrocarbon, carbon monoxide, and nitric oxide emissions respectively for all the vehicles.

Figure 4 shows the overall average of all five vehicles.

Conclusions

As seen by Figure 4, hydrocarbon emissions changed very little, dropping off slightly as speed is increased to 30 and 40 miles per hour then increasing slightly as speed is further increased to 70 miles per hour.

Carbon monoxide averages drop about 40% as speed is increased to 30 miles per hour then increase to over twice the original value (at 20 mph) as speed is increased to 70 miles per hour. There is considerable variation among the different cars probably related to differences between the idle and mid-range circuits of the carburetor.

Figure 1

HYDROCARBON EMISSIONS VS. SPEED

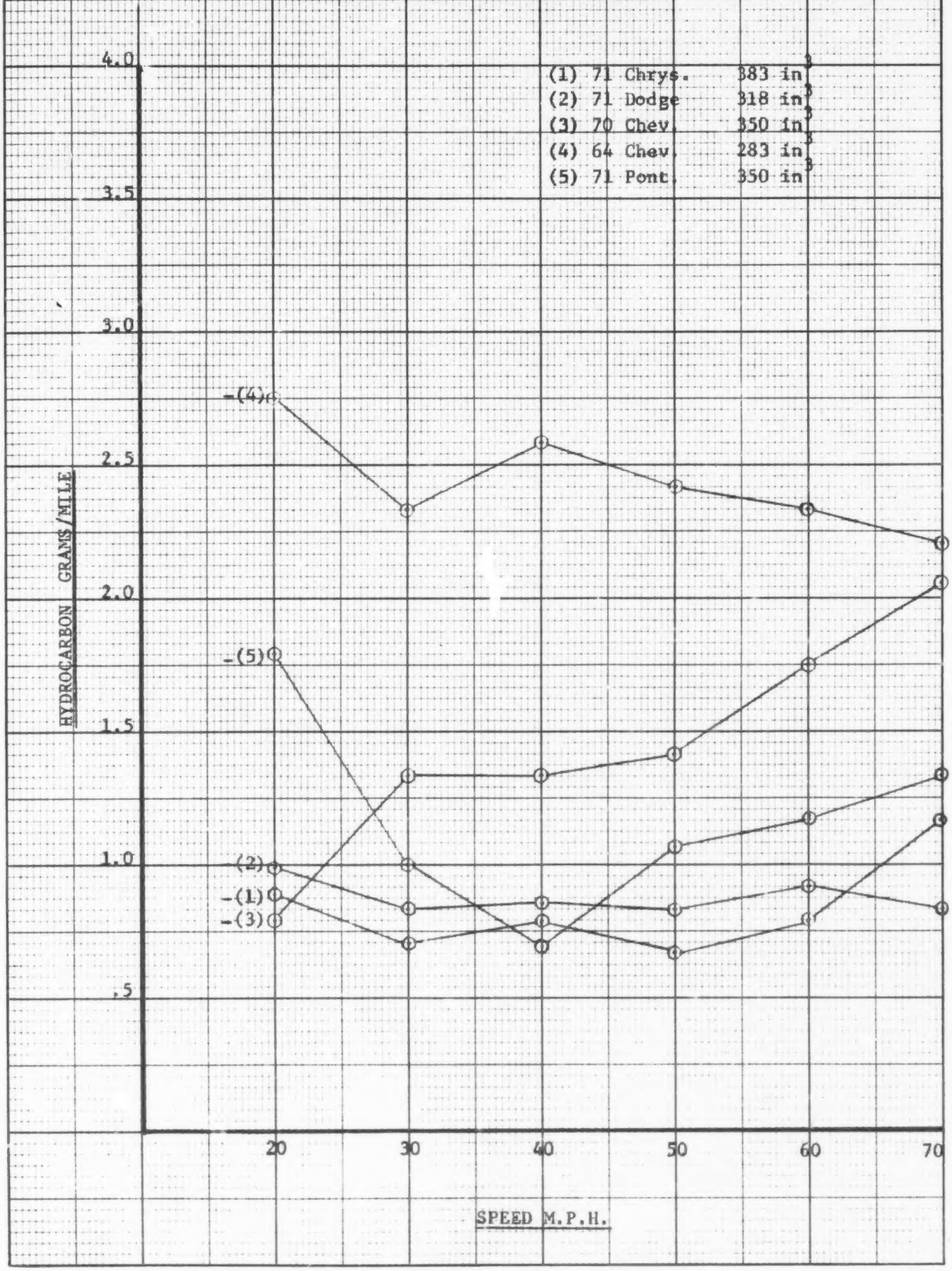
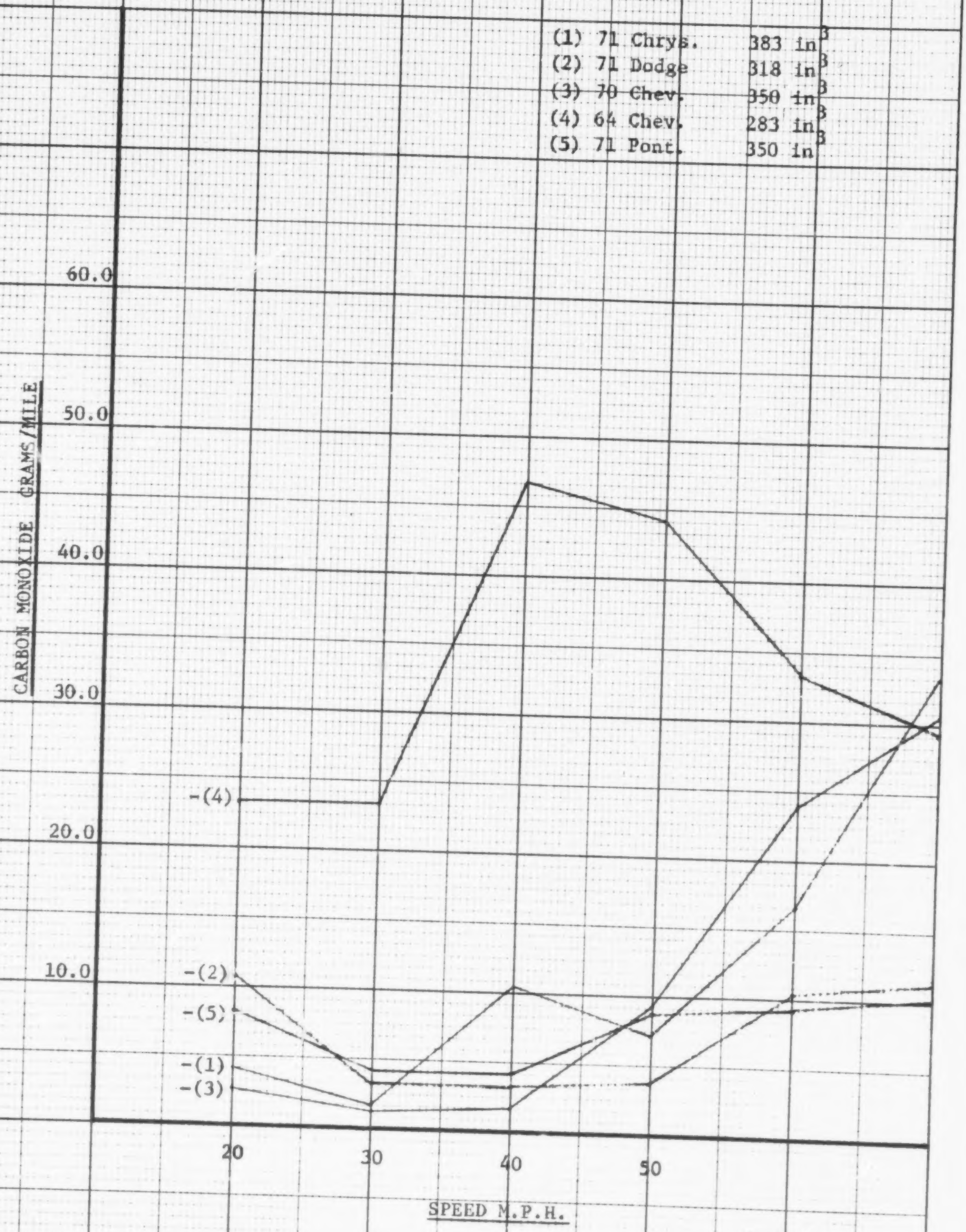


Figure 2

CARBON MONOXIDE EMISSIONS VS. SPEED



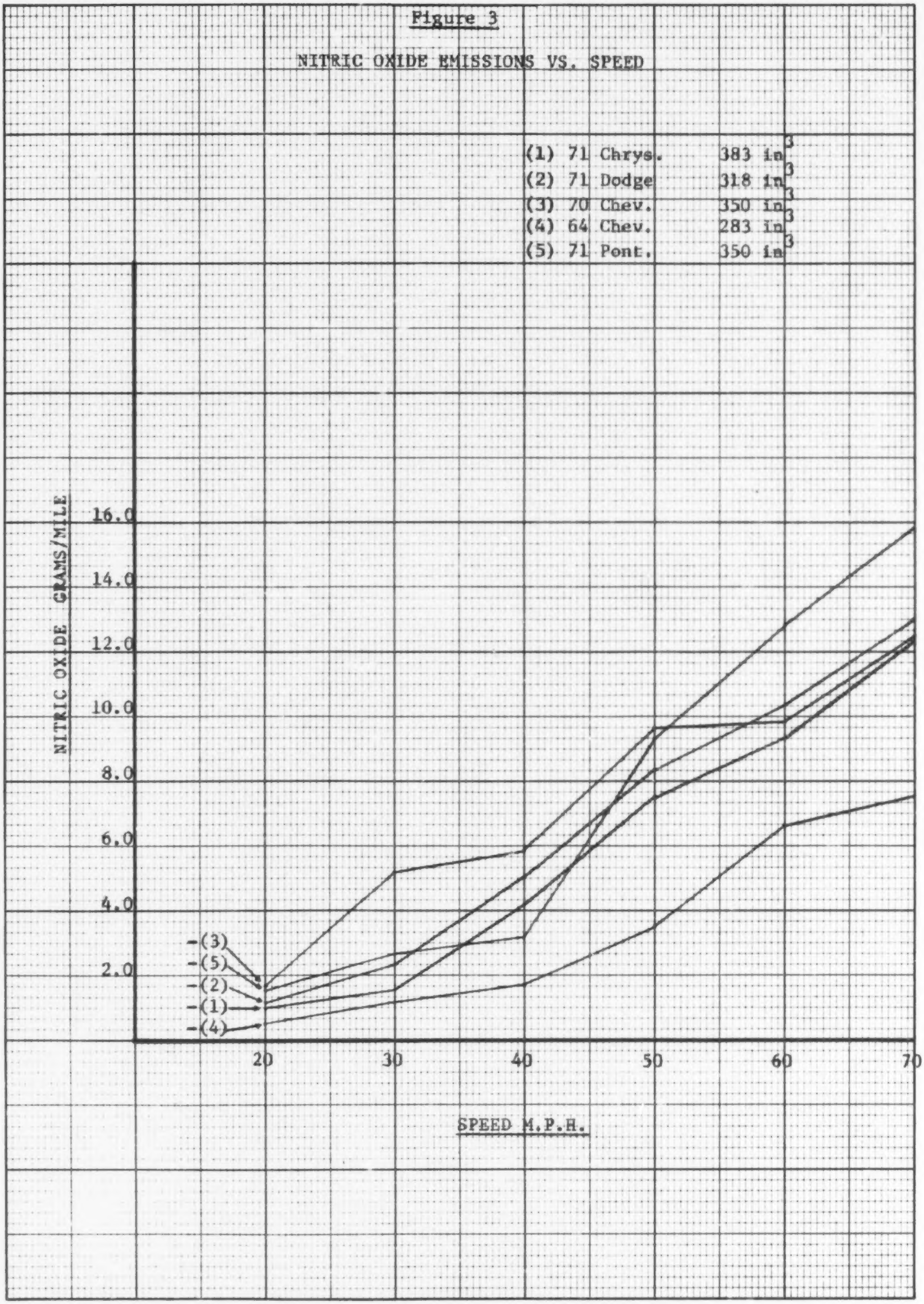


Figure 3

NITRIC OXIDE EMISSIONS VS. SPEED

Figure 4

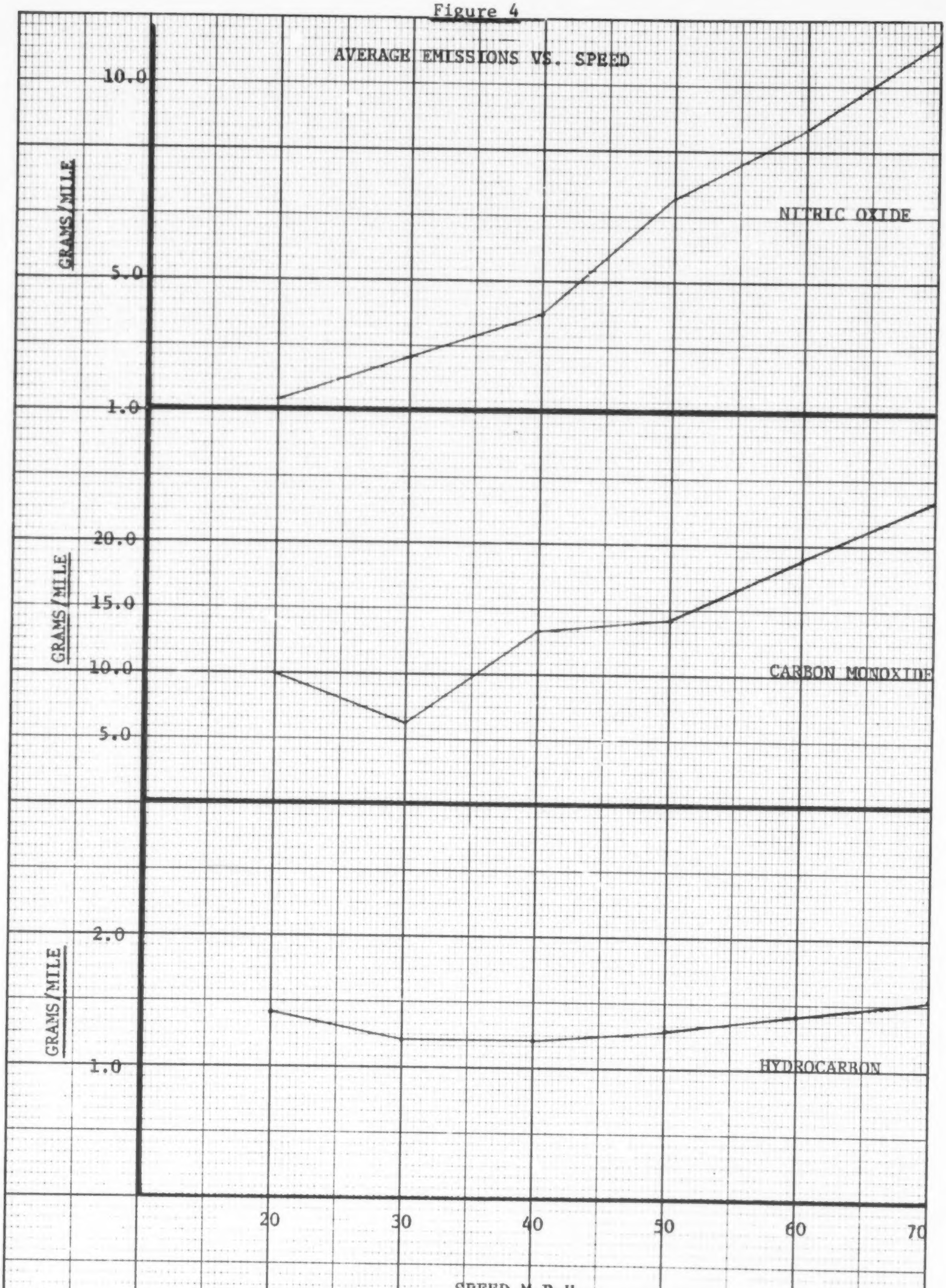
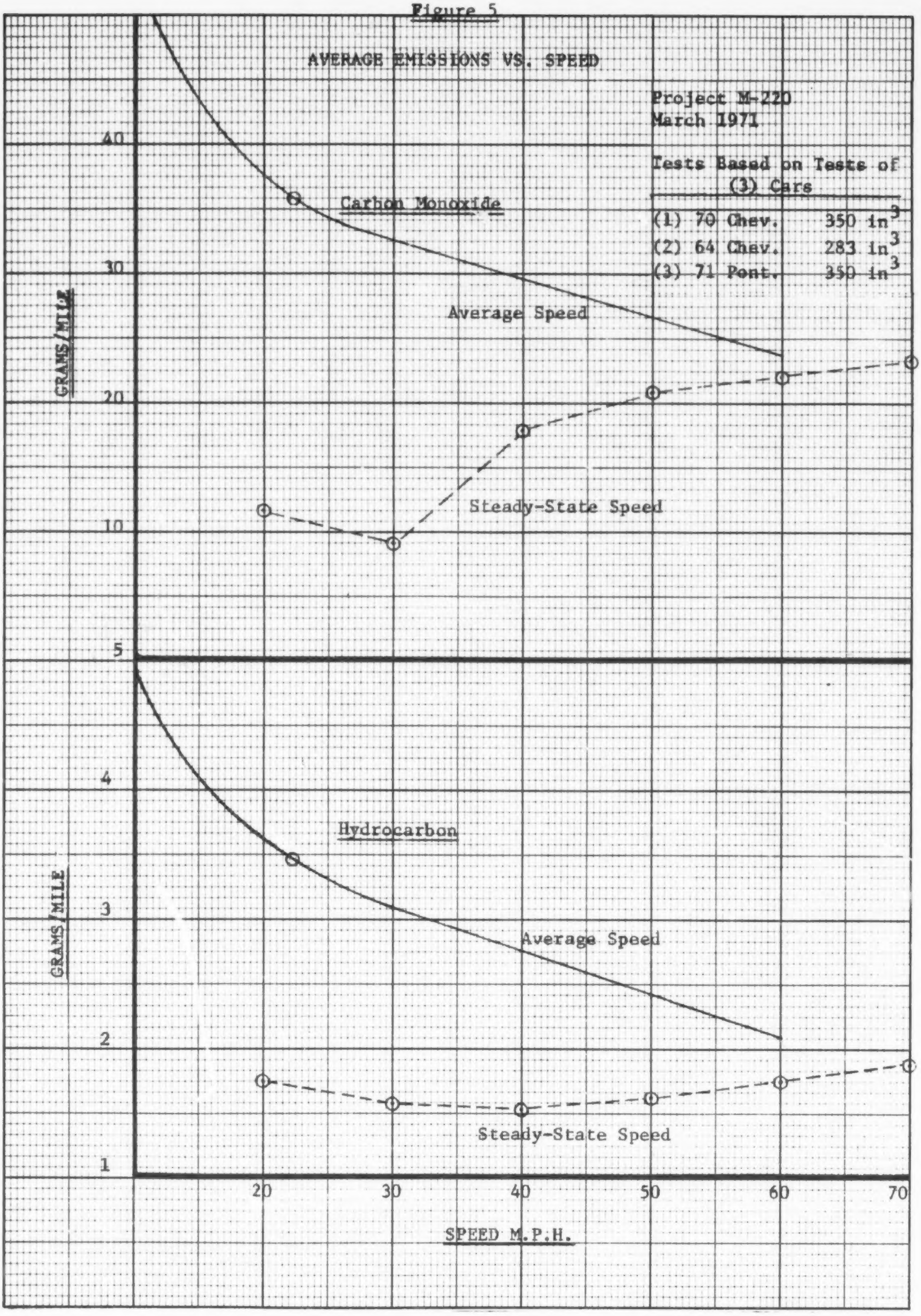

AVERAGE EMISSIONS VS. SPEED
GRAMS/MILE
10.0
5.0
1.0
NITRIC OXIDE
GRAMS/MILE
20.0
15.0
10.0
5.0
CARBON MONOXIDE
GRAMS/MILE
2.0
1.0
HYDROCARBON
20
30
40
50
60
70
SPEED M.P.H.

Figure 5



AVERAGE EMISSIONS VS. SPEED

Project M-220
March 1971

Tests Based on Tests of (3) Cars

(1) 70 Chev. 350 in^3
(2) 64 Chev. 283 in^3
(3) 71 Pont. 350 in^3

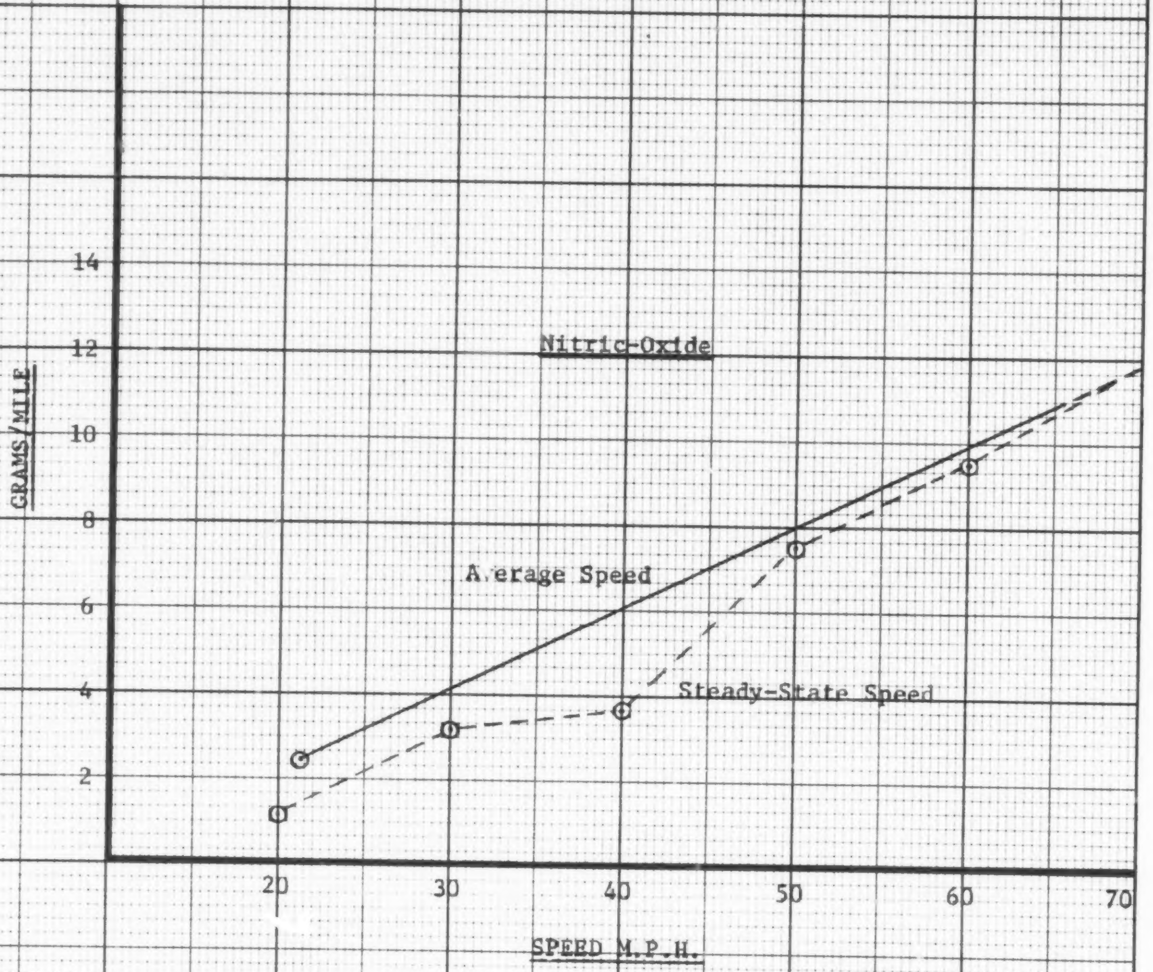
Figure 5e

AVERAGE EMISSIONS VS. SPEED (NO)

Project M-220
March 1971

Results Based on Tests of (3) Cars

(1) 70 Chev. 350 in^3
(2) 64 Chev. 283 in^3
(3) 71 Pont. 350 in^3



64-73

COMPARISON OF AUTO EXHAUST EMISSIONS FROM TWO MAJOR CITIES

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For presentation at the
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Annual Meeting, Houston, Texas
June, 1964

C-13

COMPARISON OF AUTO EXHAUST EMISSIONS FROM TWO MAJOR CITIES

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INTRODUCTION

Legislation restricting automotive emissions has been enacted or is contemplated in such widely diverse areas as California, New York, and Colorado. The drafting of fair and effective legislation requires a comprehensive knowledge of the automotive emission levels in a given community. In order to predict emission levels for a community, knowledge of the effects of traffic density, route, and climate on automotive emissions must be established. To provide a basis for developing predictions of emission levels, the U. S. Public Health Service in the summer of 1962 undertook a program of exhaust emission studies in several large cities using a new technique of direct measurement of emissions from vehicles operating under actual traffic conditions. This report presents the preliminary findings from the first two cities studied -- Los Angeles, California, and Cincinnati, Ohio.

SURVEY TECHNIQUES

Previous emission studies have been made by continuous measurements of the exhaust contaminant emissions with the vehicle operating under a fixed-mode cycle.(1,2) This mean cycle was based on a statistical study of the distribution of mode frequency, mode duration, and rate of change of the transient modes that occur over an actual traffic route believed to consist of the same proportion of each traffic classification as the whole of the area. Emphasis was thus placed on measurements of exhaust emissions under fixed-mode conditions rather than on measurements under actual road conditions. While this approach provides relative emission levels among individual vehicles or groups of vehicles, based on fixed-mode cycles, it failed to consider the effects on emissions produced by variations in traffic density, route, and climate. To overcome these limitations, emission measurements for this present study were made on vehicles equipped with a proportional sampler and driven under actual traffic conditions over selected routes in two cities.

INSTRUMENTATION

The proportional sampler used was developed by the U. S. Public Health Service(3) in 1962; this sampler is an electromechanical servo device that obtains a composite exhaust sample proportional to the engine carburetor air flow under all operating conditions. Recording, flow-integrating circuits built into the sampler provide measurements of both total sample flow and total exhaust flow. Since an absolute measure of exhaust emissions was desired, measurements of exhaust volume and sample volume as well as contaminant concentration were made for each test vehicle. Further, since both total sample and total exhaust flow were obtained, the proportionality of the sampler could be checked. Test runs that showed a deviation in proportionality of more than 3% were rerun.

Measurements of contaminant concentration were made after return of the composite sample to the laboratory. Hydrocarbons were measured by a Beckman L/B infrared analyzer Model 15A equipped with an n-hexane detector and by a Beckman Model 109 flame ionization detector. Carbon monoxide and carbon dioxide were measured by Beckman L/B Model 15A infrared analyzers sensitized with carbon monoxide and carbon dioxide respectively. Oxides of nitrogen were measured by means of a modified Saltzman technique.

VEHICLE AND ROUTE SELECTION

Emission measurements for all vehicles tested were made under average traffic conditions. To establish the effects of traffic density on emission levels, five vehicles were tested under both peak and offpeak traffic conditions. Because of the difficulties in private vehicle procurement and the increase in test time required for this direct measurement procedure, twenty privately owned vehicles and twenty rental vehicles were tested in each city. The privately owned vehicles were randomly selected by standard statistical techniques from an available population of 300 to 400 cars that were believed, on the basis of the income differential of the vehicle owners, to be as nearly representative as possible of each city's car population, Tables 1, A and B. The distribution of vehicles ages for the random vehicle samples in both cities covered an 8 year range, varying from 1955 to 1963 models. The random samples included both six and eight-cylinder engines with both manual and automatic transmissions. Manual transmissions in each random sample accounted for 20 to 30 per cent of the sample population. The rental vehicles tested were late model Fords and Chevrolets with automatic transmissions. This set of vehicles, being easier to procure than the random sample vehicles, was used to furnish background emission data to the random samples to further verify the trends developed. The test vehicles were operated on the fuel normally used by the vehicle owner.

The requirement for developing a driving cycle representative of the traffic conditions for each specific area under study was eliminated by selecting first, traffic routes that represent the basic categories of traffic in all urban areas and second, a measurable vehicle parameter associated with the various route categories that can be reliably related to emission measurements. Four traffic categories were established: business, residential, arterial and freeway. Exhaust emissions are expressed both as the concentrations of contaminants and as pounds of contaminants emitted per vehicle mile traveled. This latter method of expressing emissions was selected for two reasons: 1) it is consistent with average traffic volume data for major metropolitan areas, i.e., vehicle miles traveled; and (2) it can be related directly to the useful work performed by the automobile under a given series of driving conditions.

EVALUATION TECHNIQUE

Analysis of the emission data for individual vehicles indicated that average vehicle speed is a measurable parameter that provides an adequate measure or index of emissions from a specific route. This parameter is related to traffic volume and route conditions, since the average vehicle speed reflects the engine power demands required by variations in topography of the route as well as acceleration, deceleration, cruise and idle driving modes.

Because of the variations inherent among vehicles, emission levels in different cities can be compared only by a statistical method that considers both vehicle speed and emission levels, expressed either as concentration or as total weight emitted per vehicle mile. Preliminary evaluation of the data for emissions of hydrocarbon, carbon monoxide, and carbon dioxide indicates that this empirical relationship between speed and emission level can be best satisfied by a power function. The emission data for individual vehicles were therefore combined for the four routes and fitted to a power function ($Y=AX^b$) by the least squares regression technique. Correlation coefficients were determined to establish the degree of fit of each class of emission measurements for both cities. The significance of emission level-average speed trends in the cities was established by an analysis of co-variance.

Emissions in pounds per vehicle mile traveled were computed by calculating the total weight of contaminants emitted over each route from concentration and total exhaust flow values, and dividing by route length in miles. This calculation assumed a hydrogen to carbon ratio of 1.85 to 1. Since the hydrogen to carbon ratio depends on exhaust composition, the exhausts produced by fuels of varying composition were analyzed chromatographically to establish the hydrogen to carbon ratio. This assumption, therefore, should not produce an error greater than ± 5% in calculated emission weights.

RESULTS

Comparison of Emissions by Concentration

The initial approach to a comparison of emission levels in the two cities was based on exhaust emission concentrations. Figures 1 through 4 indicate the regression fit of the power function of concentration data for the combined four routes versus average vehicle speed plotted on scatter diagrams of the emission data for hydrocarbon, carbon monoxide and carbon dioxide. Figures 1 and 3 represent the random vehicle sample; Figures 2 and 4, the rental vehicle sample.

Variation in concentration of exhaust hydrocarbons with vehicle speed for the combined four traffic routes in the two cities is shown in Figures 1 and 2. The trends for both cities, based on either the infrared or the flame ionization analyses, show a general decrease in hydrocarbon concentration with increasing average vehicle speed. The effect of average vehicle speed on carbon monoxide and carbon dioxide concentrations in the exhaust is shown in Figures 3 and 4. As would be expected from the hydrocarbon trend, the carbon monoxide concentration decreases and the carbon dioxide concentration increases with increasing average vehicle speed.

Correlation coefficients for the empirical relationship between average route speed and concentration of hydrocarbon, carbon monoxide and carbon dioxide for each city, Table 2, indicate that although the correlations are statistically valid, the degree of correlation is only fair. In contrast to the relationships for these three contaminants, oxides of nitrogen concentrations showed no such variation with average vehicle speed, remaining essentially constant with increase in average speed. The relationship with air-fuel ratio, however, as expected on the basis of previous data, showed an increase in oxides of nitrogen concentration with increasing or enleaning air-fuel ratios, Figures 5 and 6. Further, the correlation coefficient for the relationship of oxides of nitrogen concentration with air-fuel ratio, Table 2, indicated that the degree of correlation is excellent.

Within the vehicle-speed range of this study, the total volume of air consumed by the engine, when expressed as cubic feet per mile traveled, decreases with increasing average speed, as shown in the plot of average vehicle speed versus air consumption, Figure 7. This trend is consistent for both cities and shows a good correlation, Table 2.

Comparison of Emissions by Weight

The second comparison of emission levels with average route speed was made on the basis of pounds of contaminant emitted per vehicle mile traveled, Figures 8 through 11. Again, the regression fit of the power function of emission in pounds per vehicle mile versus average route speed was plotted on scatter diagrams of the emission data for the four combined routes. Figures 8 and 10 represent the random vehicle sample; Figures 9 and 11 cover the rental vehicle sample.

The weight of exhaust hydrocarbon and carbon monoxide emitted per vehicle mile of travel decreases with increase in average vehicle speed, Figures 8 through 11. This relationship is consistent for both cities. The effect of average vehicle speed on both hydrocarbon and carbon monoxide emissions is proportionately greater during the low-speed condition below 20 mph. This speed range represents the residential and business routes; the high percentage of stop and start driving required in these traffic conditions causes an increase in acceleration, deceleration, and idle operation and accounts for the higher emission rates and vehicle air consumption in this lower average speed range.

Figures 9 and 11 indicate the effect of vehicle speed on pounds of carbon dioxide emitted per vehicle mile. As the figures show, increase in vehicle speed produces a consistent decrease in pounds of carbon dioxide emitted per vehicle mile. This is in contrast with the preceding concentration trend which indicated a slight increase in carbon dioxide concentration with increase in average speed. This effect of the greater decrease in air consumption per mile overriding the smaller increase in carbon dioxide concentration becomes apparent when the emissions are presented on a weight per mile basis instead of a concentration basis.

The relationship between average route speed and emission levels expressed as pounds per vehicle mile shows a good correlation, in contrast to the fair correlation shown for the emission levels by concentration, Table 2. The correlation coefficients for emissions on a weight basis range from 0.57 to 0.84, whereas the correlation coefficients on a concentration basis range from 0.25 to 0.61. This would be expected since the emission levels calculated as weight per vehicle mile more nearly reflect the work performed by the engine.

Again, as with oxides of nitrogen emission values based on concentration, mass oxides of nitrogen emissions expressed as pounds per vehicle mile traveled show no relationship with average vehicle speed, remaining essentially constant with increase in average speed. The relationship with air-fuel ratio, however, again indicates an increase in mass emission of oxides of nitrogen with increasing air-fuel ratio, Figures 12 and 13. Correlation coefficients for this relationship, Table 2, indicate the same high degree of correlation as with the values based on concentration.

Variation Among Vehicles

The data indicate the scatter in the plots of concentration and of contaminant weight per vehicle mile versus average route speed results fundamentally from the extreme variation in emission levels among vehicles and not from poor correlations between emission level and average route speed. This is shown in Figures 14 through 16, in which regression lines of the emission data for hydrocarbons and carbon monoxide in pounds per vehicle mile versus average route speed are plotted for each individual vehicle in the Los Angeles random vehicle sample. As these figures show, each vehicle follows the same general power function of pounds of emission per vehicle mile versus average vehicle speed, forming a family of curves with generally the same slope. Specifically, the pooled estimate of variance of the data about the regression lines for individual cars is small, varying from 0.0024 to 0.0061, in contrast to the variance of the total emission data about a single regression line, which ranges from 0.035 to 0.115. This order of magnitude difference in variance substantiates the premise that the spread of emission levels results basically from the differences among individual vehicles.

Comparison of Emissions in the Two Cities

To establish the significance of the emission weight versus average speed relationships in the two cities, an analysis of co-variance was used to determine whether the regression lines for pounds of contaminant emissions per vehicle mile versus average speed differed significantly, Figures 8 and 10. This analysis was based on the random vehicle samples since they more nearly represent the actual vehicle distribution found in the respective cities. The rental vehicle sample was not used because it is definitely biased by the limited age, transmission type, and vehicle make that compose its vehicle distribution.

For hydrocarbons measured by the flame ionization analyzer, and for carbon monoxide and carbon dioxide, the regression lines for the two cities were not significantly different at the 95% confidence level. For hydrocarbons measured by nondispersive infrared analyzer in the two cities, however, the regression lines were statistically different. This differance apparently results from the variation in the response of this hydrocarbon instrument to different hydrocarbon compounds appearing in automobile exhaust. Differences in the gasoline used in Cincinnati and Los Angeles may be responsible for such differences in the products of combustion. Figure 17, which shows the ratio of nondispersive infrared response to flame ionization response, indicates that this ratio increases at a higher rate, with increasing vehicle speed, for Cincinnati than for Los Angeles. This change in ratio explains the apparent different rates of decrease of hydrocarbons emitted as vehicle speed increases, Figures 1 and 8. In Cincinnati the rate of decrease is less with the result that the difference in pounds of hydrocarbon emitted, measured with the nondispersive infrared analyzer, becomes increasingly greater between these cities as vehicle speed increases. Cincinnati data show the highest value. On this basis, it is believed that the statistical difference shown between Cincinnati and Los Angeles for the pounds of hydrocarbon per vehicle mile, measured by this method, is an instrument characteristic and therefore is not real.

Effects of Peak Versus Offpeak Traffic

Traffic density is reflected in both engine power demand and average vehicle speed and as such influences exhaust concentration levels and engine air consumption. A special study of peak versus offpeak traffic conditions was undertaken to evaluate this effect.

Five vehicles were run on the business, arterial, and freeway routes in Los Angeles, under both peak and offpeak traffic conditions. The data indicate that the mean emission level of test vehicles varies about the plot for the weight per mile versus average speed curve. Because of this variation, comparisons between peak and offpeak values of weight of emission per mile cannot be made directly with the population mean value. Comparisons can be made, however, between the ratios of measured peak to offpeak weight emission per mile values with the same ratio values calculated using the regression line for the specific contaminant and speed. Table 3 shows the measurements in terms of mean values for the freeway route in Los Angeles. Since the arterial and business routes indicated no significant difference in speed between peak and offpeak traffic conditions, these routes were not used in the comparison. The data indicate that the two ratios, i.e., calculated and measured, are the same for hydrocarbon measured by both the flame ionization analyzer or the nondispersive infrared analyzer and for carbon monoxide. It is concluded that the effect of peak versus offpeak traffic on contaminant emission is basically a function of the changes in average speed for the route under consideration and does not affect the pound per vehicle mile emission level at the specific measured route speed.

SUMMARY

Although the emission results presented for Los Angeles and Cincinnati are preliminary, since studies are continuing in other cities, certain conclusions can be made on the basis of the present data.

1. Emissions, expressed as pounds of contaminant emitted per vehicle mile traveled, are a function of average route speed regardless of the characteristics of the specific route, and can be best shown as a logarithmic function of pounds of contaminant emitted per vehicle mile versus average vehicle speed.

2. Emissions expressed as concentration are a less valid measurement of exhaust atmospheric contamination than emissions expressed as pounds per vehicle mile traveled. The reason is believed to be the variability of combustion air consumption among vehicles and variability among route characteristics.

3. The road emission data expressed as a logarithmic function of pounds of contaminant emitted per vehicle mile versus average route speed show no significant difference between Los Angeles and Cincinnati.

4. The effect of peak versus offpeak traffic on emissions, expressed as pounds of contaminant emitted per vehicle mile traveled, is basically a function of the change in average route speed.

REFERENCES

1. Hass, G. C., "Report on Exhaust Emissions from 194 California Vehicles," California Motor Vehicle Pollution Control Board, June 19, 1962.

2. Way, G., Fagley, W. S., "Field Survey on Exhaust Gas Composition," SAE Annual Meeting, Detroit, Michigan, January 13, 1958.

3. Smith, R., Rose, A. H., Jr., and Kruse, R., "An Auto Exhaust Proportional Sampler," APCA Annual Meeting, Detroit, Michigan, June, 1963.

TABLE 1A

DESCRIPTION OF CINCINNATI TEST VEHICLES

RANDOM SAMPLE

CAR NO.	MAKE	YEAR	ODOMETER	CYLINDERS	DISPLACEMENT	TRANSMISSION
1	Olds.	1960	48,623	V8	371	Auto.
2	Chev.	1960	22,680	V8	283	Auto.
3	Chev.	1959	45,345	6	236	Man.
4	Rambler	1961	12,577	6	196	Man.
5	Chev.	1961	25,176	6	236	Man.
6	Ford	1956	36,069	V8	292	Auto.
7	Buick	1961	15,133	V8	215	Auto.
8	Ford	1957	65,464	V8	292	Auto.
9	Ford	1959	38,709	V8	292	Auto.
10	Merc.	1960	49,306	V8	312	Man.
11	Chev.	1957	54,174	V8	283	Auto.
12	Ford	1959	42,874	V8	292	Auto.
13	Chev.	1959	36,797	6	236	Auto.
14	Falcon	1960	42,611	6	144	Auto.
15	Chev.	1959	36,727	6	236	Auto.
16	Pontiac	1956	59,454	V8	317	Auto.
17	Olds-F85	1963	4,202	V8	215	Auto.
18	Rambler	1962	4,390	V8	327	Auto.
19	Chev.	1958	40,380	V8	283	Auto.
20	Ford	1957	49,779	V8	272	Auto.

TABLE 1B

DESCRIPTION OF LOS ANGELES TEST VEHICLES

RANDOM SAMPLE

CAR NO.	MAKE	YEAR	ODOMETER	CYLINDERS	DISPLACEMENT	TRANSMISSION
1	Olds.	1960	28,024	V8	292	Auto.
2	Chev.	1960	58,712	V8	283	Auto.
3	Falcon	1960	22,343	6	144	Auto.
4	Chevy II	1963	8,419	6	194	Auto.
5	Ford	1955	54,521	6	223	Auto.
6	Rambler	1962	6,318	6	196	Auto.
7	Chev.	1959	14,741	V8	348	Man.
8	Ford	1955	31,401	6	223	Man.
9	Chev.	1960	18,586	6	236	Auto.
10	Ford	1956	70,070	V8	272	Auto.
11	Plymouth	1959	72,737	V8	318	Auto.
12	Ford	1962	7,686	V8	352	Auto.
13	Chev.	1961	18,937	6	236	Auto.
14	Falcon	1960	38,750	6	144	Man.
15	Chevy II	1962	16,285	6	194	Man.
16	Olds.	1955	90,944	V8	324	Man.
17	Chev.	1959	138,672	V8	283	Auto.
18	Chev.	1956	62,663	V8	283	Man.
19	Merc.	1956	59,889	V8	312	Auto.
20	Falcon	1961	21,054	6	144	Auto.

TABLE 2

CORRELATION COEFFICIENTS

RELATIONSHIP	EMISSIONS							
	CONCENTRATION ppm				WEIGHT pounds/vehicle mile			
	CINCINNATI		LOS ANGELES		CINCINNATI		LOS ANGELES	
	RANDOM SAMPLE	RENTAL SAMPLE	RANDOM SAMPLE	RENTAL SAMPLE	RANDOM SAMPLE	RENTAL SAMPLE	RANDOM SAMPLE	RENTAL SAMPLE
HYDROCARBON VS. SPEED								
Hexane	0.302	0.388	0.506	0.561	0.686	0.720	0.683	0.697
FIAD	0.369	0.491	0.483	0.476	0.685	0.764	0.654	0.688
CO VS. SPEED	0.347	0.706	0.510	0.611	0.572	0.841	0.630	0.716
CO_2 VS. SPEED	0.247	0.601	0.476	0.430	0.623	0.658	0.581	0.613
NO_x VS. A/F RATIO	0.800	0.749	0.839	0.605	0.737	0.578	0.778	0.402
AIR FLOW VS. SPEED	0.675	0.746	0.654	0.677	0.675	0.746	0.654	0.677

TABLE 3

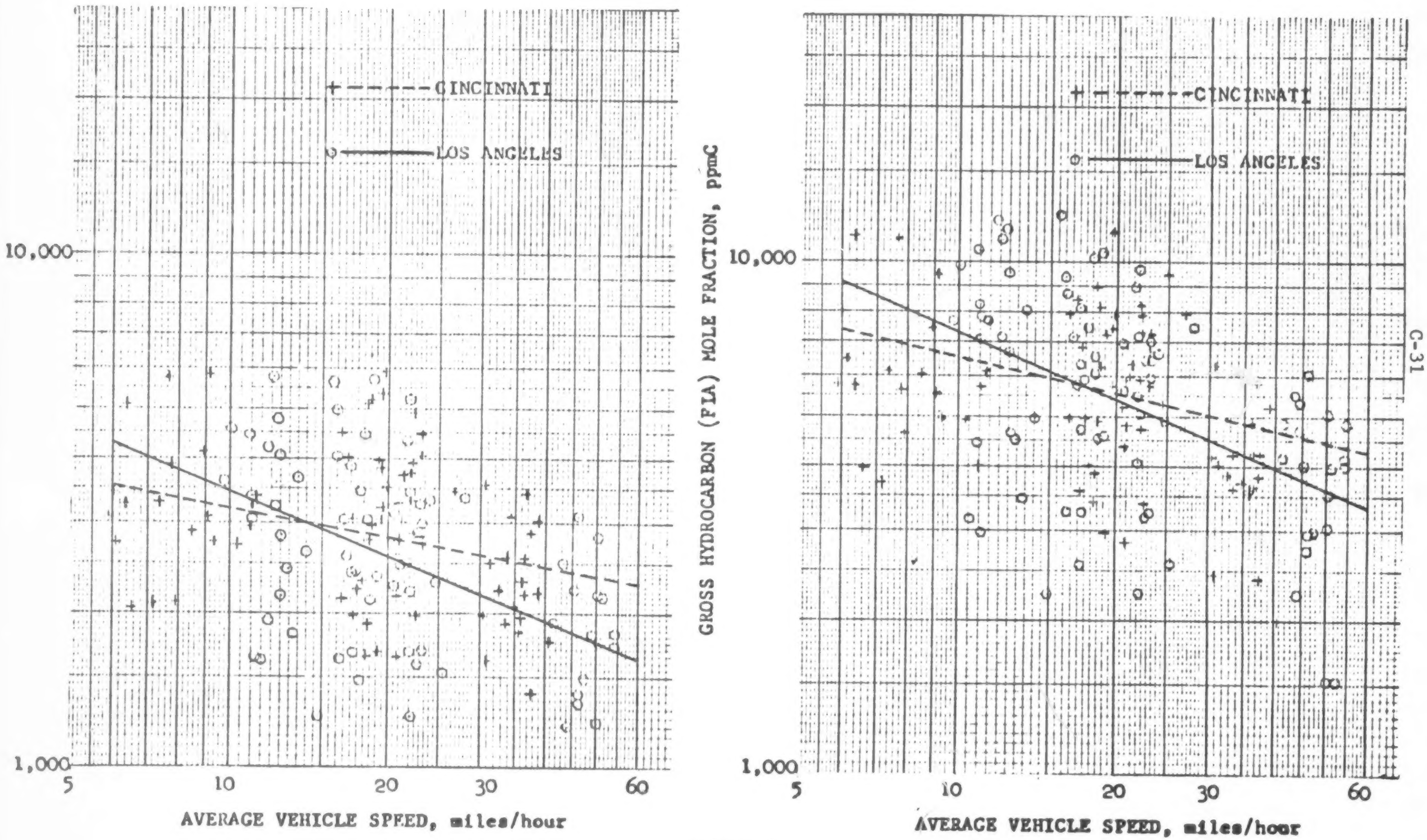
ROAD EMISSION MEASUREMENTS FOR PEAK AND OFFPEAK TRAFFIC

LOS ANGELES FREEWAY ROUTE

Measurement	Off Peak	Peak	Measured Ratio Peak/Offpeak	Calculated Ratio Peak/Offpeak
Avg. Speed (MPH)	45.2	23.0		
Air Consumption (SCF/mi.)	50.1	51.5		
Hydrocarbon, ppmC, NDIR	1620	2250		
Hydrocarbon, lbs/mi., NDIR	0.00297	0.00418	1.41	1.59
Hydrocarbon, ppmC, FIA	3210	4720		
Hydrocarbon, lbs/mi., FIA	0.00591	0.00909	1.54	1.61
CO, %, NDIR	1.62	2.68		
CO, lbs/mi., NDIR	0.0612	0.1040	1.70	1.89

Route Length = 4.97 miles

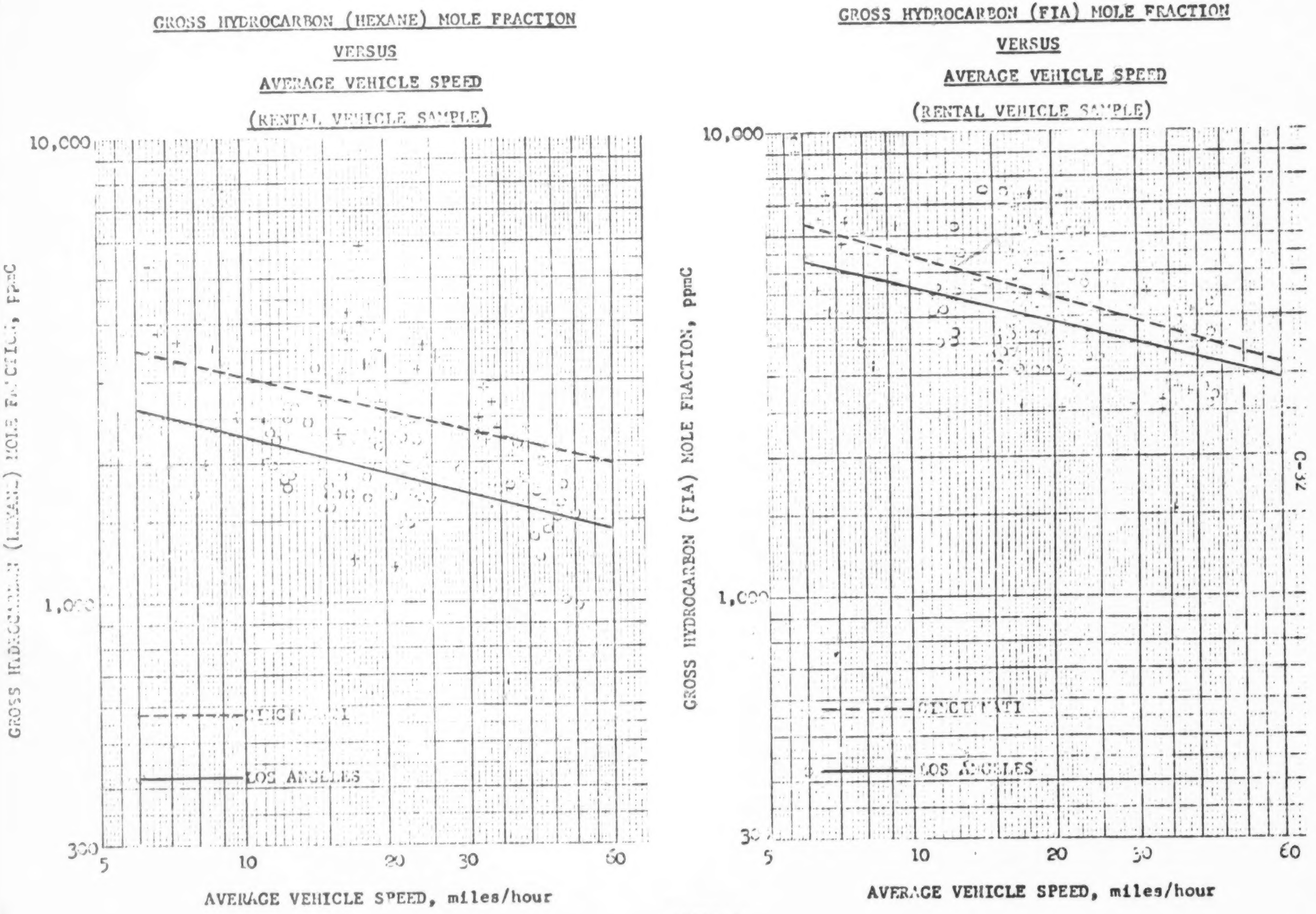
Mean Values for 5 cars



GROSS HYDROCARBON (HEXANE) MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RANDOM VEHICLE SAMPLE)

GROSS HYDROCARBON (FIA) MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RANDOM VEHICLE SAMPLE)

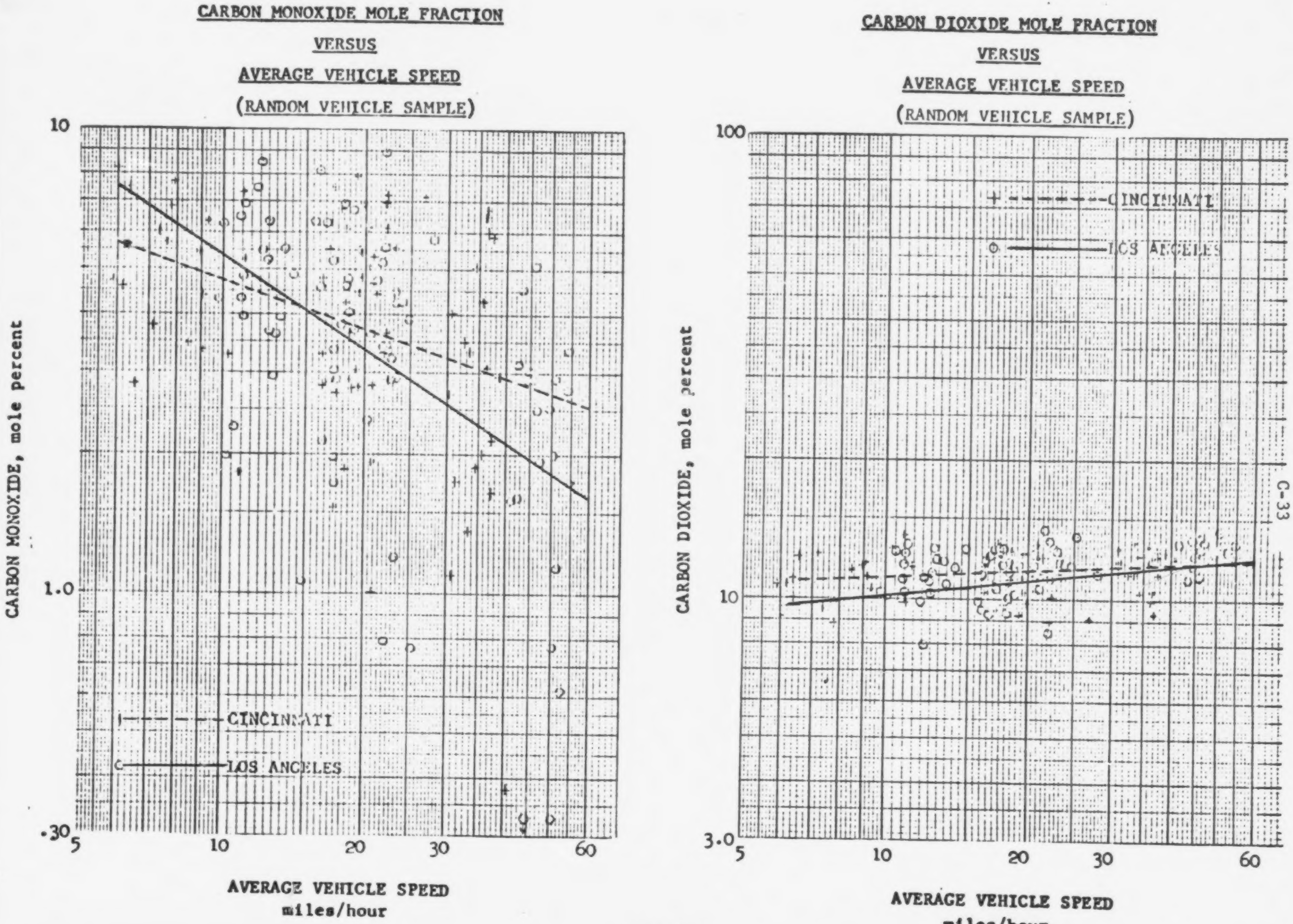
FIGURE 1



GROSS HYDROCARBON (HEXANE) MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RENTAL VEHICLE SAMPLE)

GROSS HYDROCARBON (FIA) MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RENTAL VEHICLE SAMPLE)

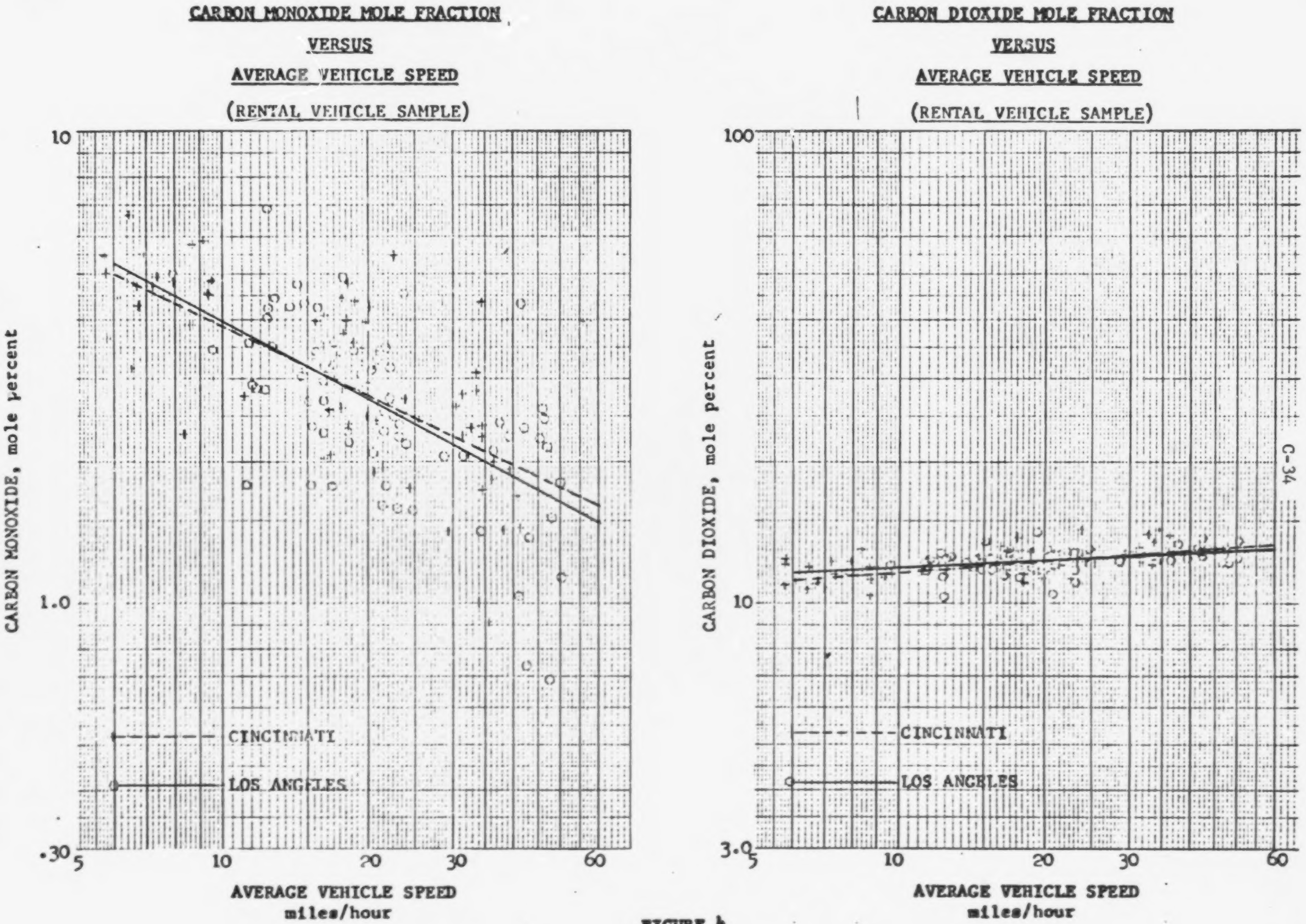
FIGURE 2



CARBON MONOXIDE MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RANDOM VEHICLE SAMPLE)

CARBON DIOXIDE MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RANDOM VEHICLE SAMPLE)

FIGURE 3



CARBON MONOXIDE MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RENTAL VEHICLE SAMPLE)

CARBON DIOXIDE MOLE FRACTION VERSUS AVERAGE VEHICLE SPEED (RENTAL VEHICLE SAMPLE)

FIGURE 4

OXIDES OF NITROGEN MOLE FRACTION
VERSUS
AIR-FUEL RATIO
(RANDOM VEHICLE SAMPLE)

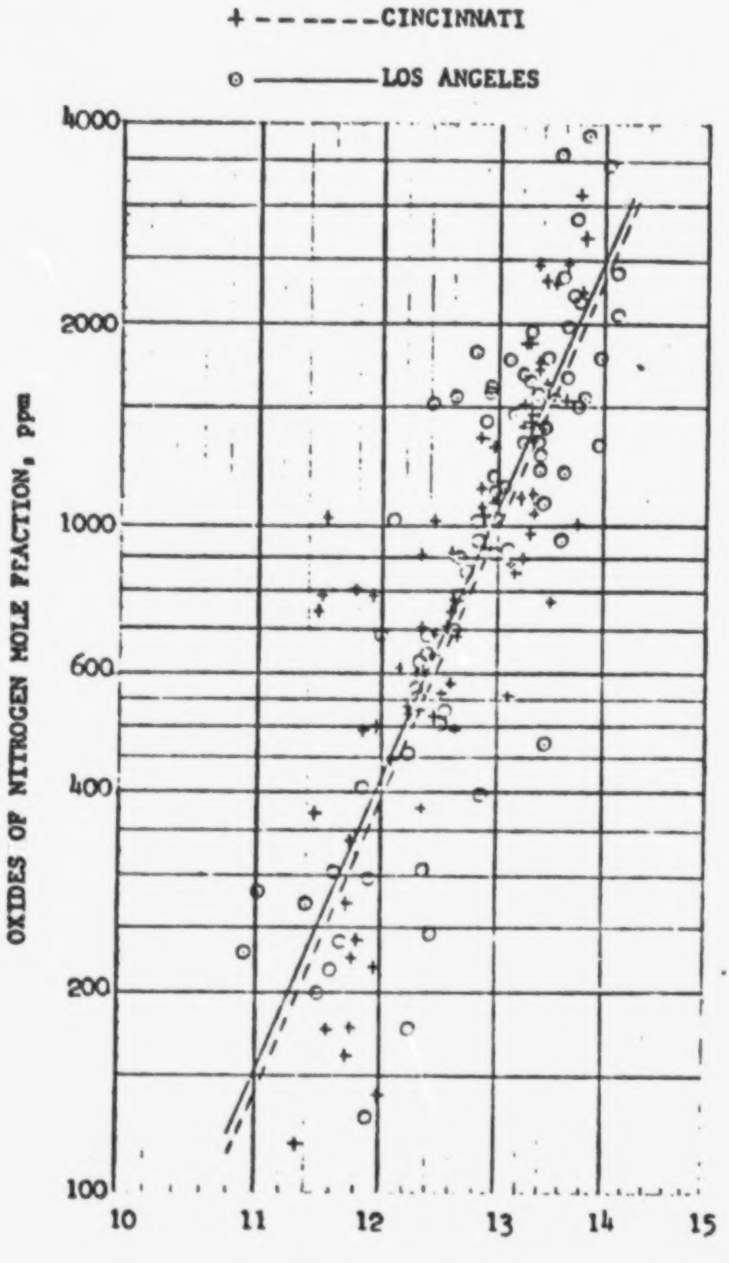


FIGURE 5

OXIDES OF NITROGEN MOLE FRACTION
VERSUS
AIR-FUEL RATIO
(RENTAL VEHICLE SAMPLE)

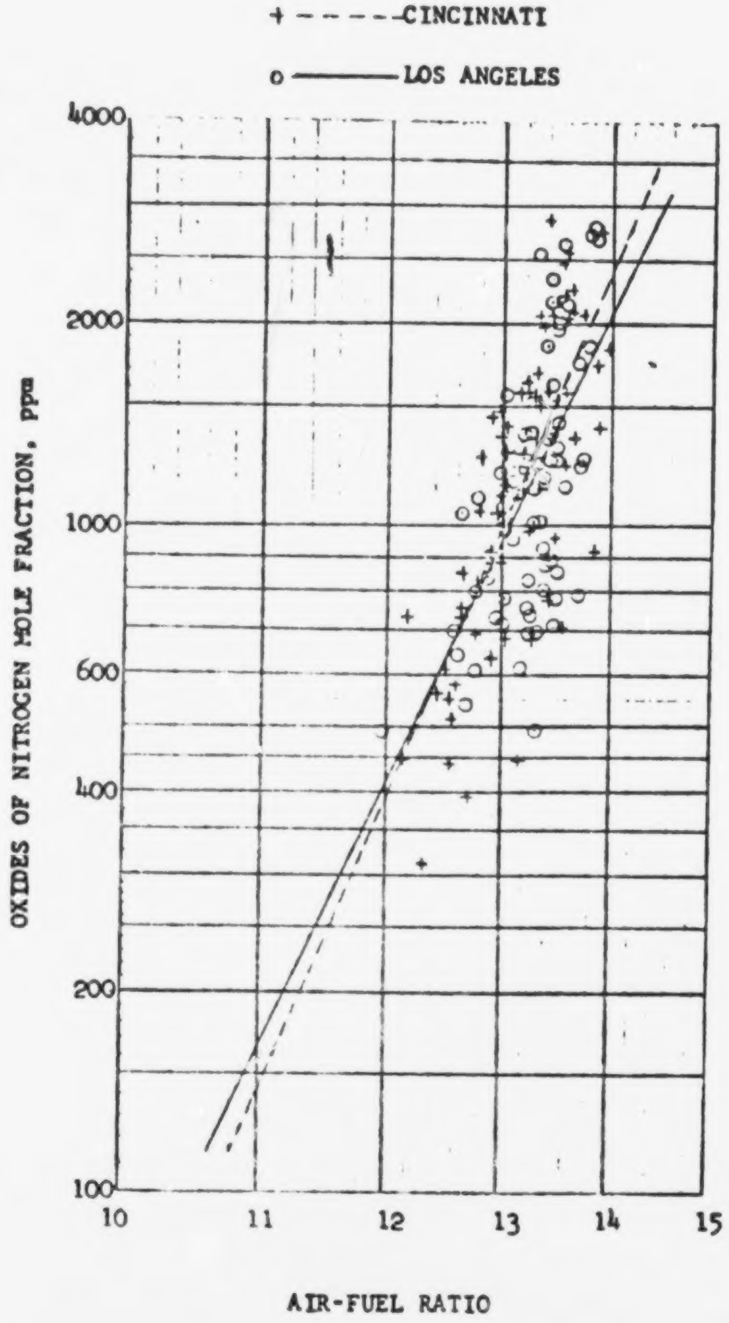


FIGURE 6

VEHICLE AIR CONSUMPTION PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RANDOM VEHICLE SAMPLE)

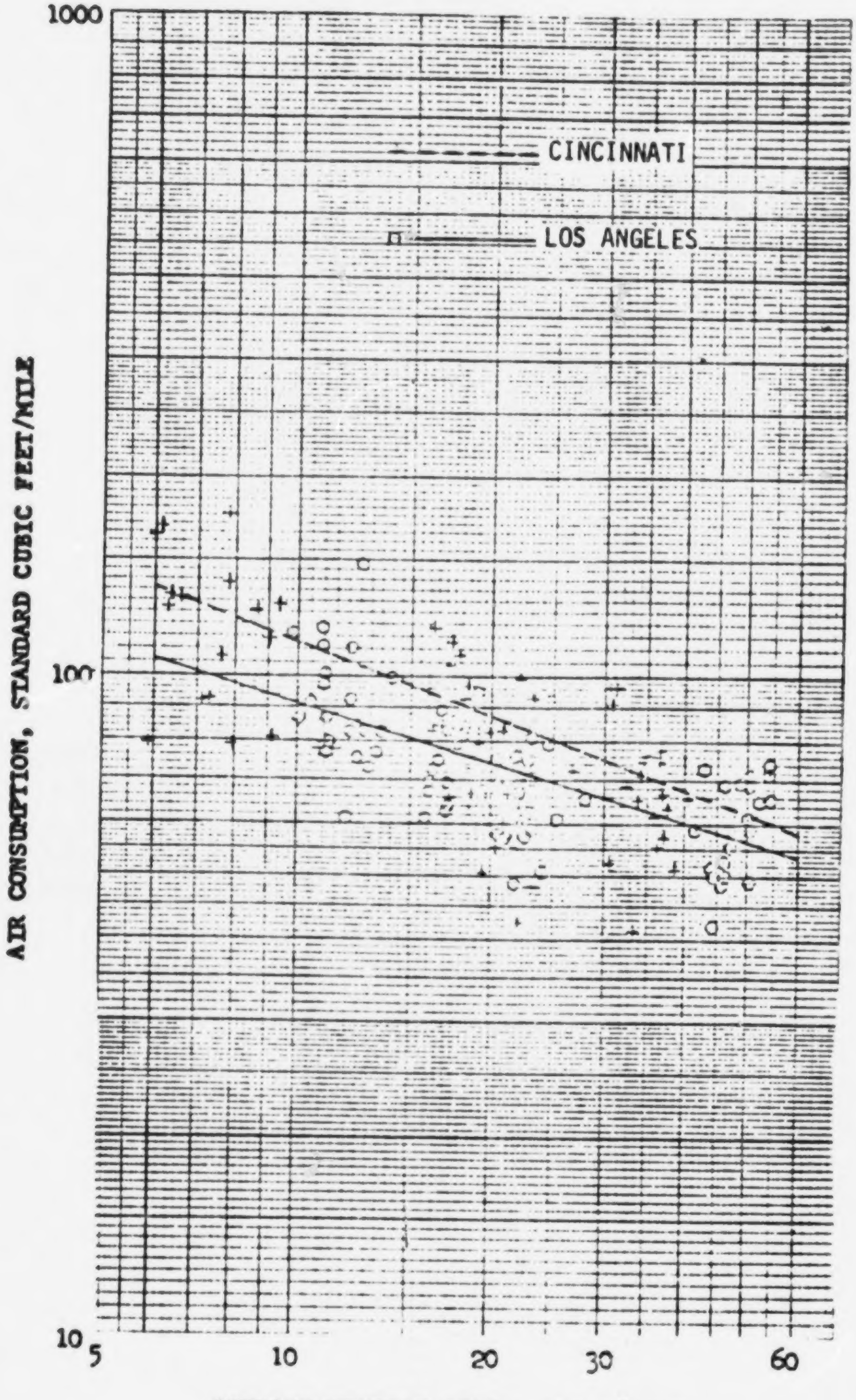
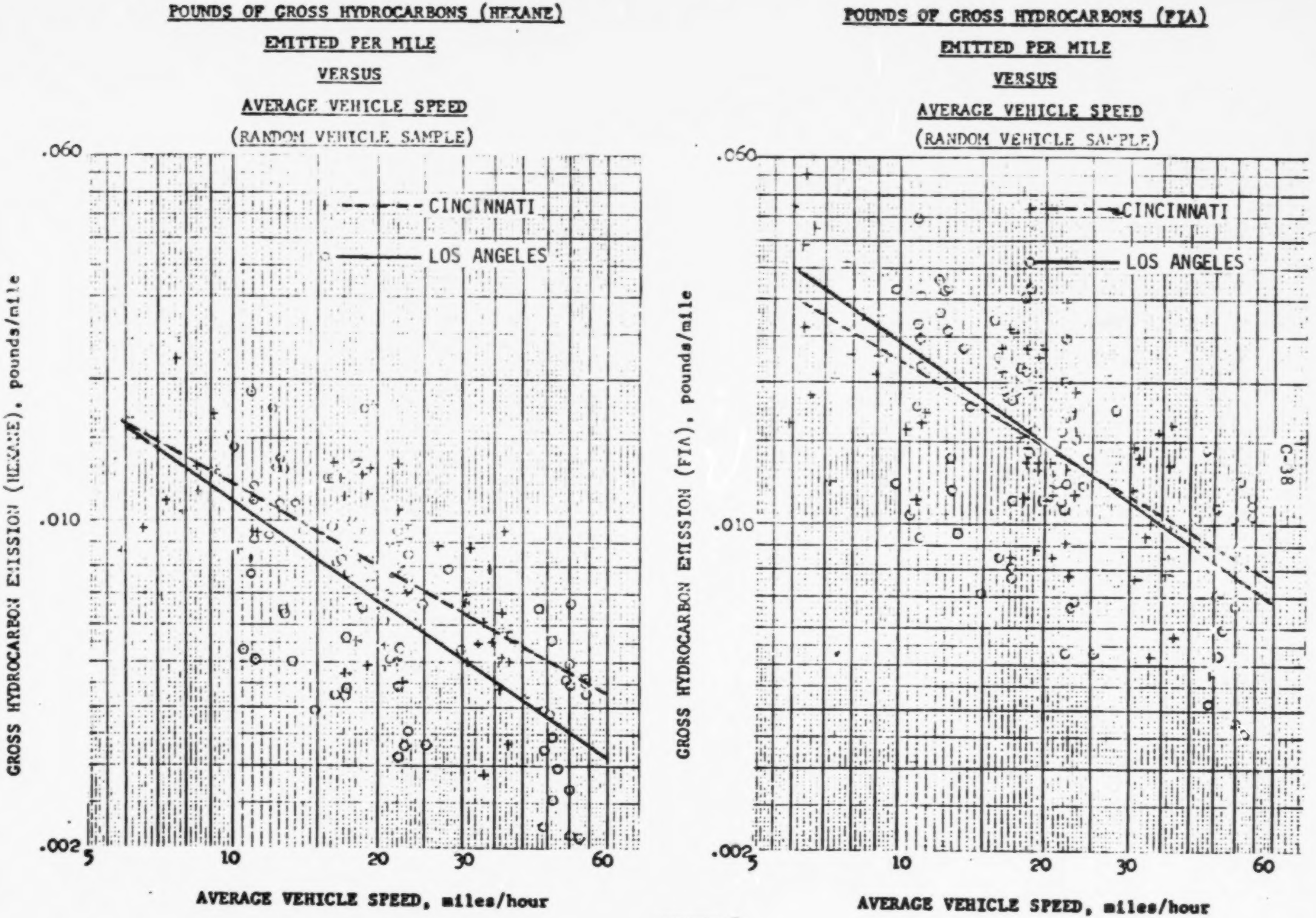


FIGURE 7



POUNDS OF GROSS HYDROCARBONS (HEXANE)
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RANDOM VEHICLE SAMPLE)

POUNDS OF GROSS HYDROCARBONS (FIA)
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RANDOM VEHICLE SAMPLE)

FIGURE 8

POUNDS OF GROSS HYDROCARBON (HEXANE)
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RENTAL VEHICLE SAMPLE)

POUNDS OF GROSS HYDROCARBONS (FI
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RENTAL VEHICLE SAMPLE)

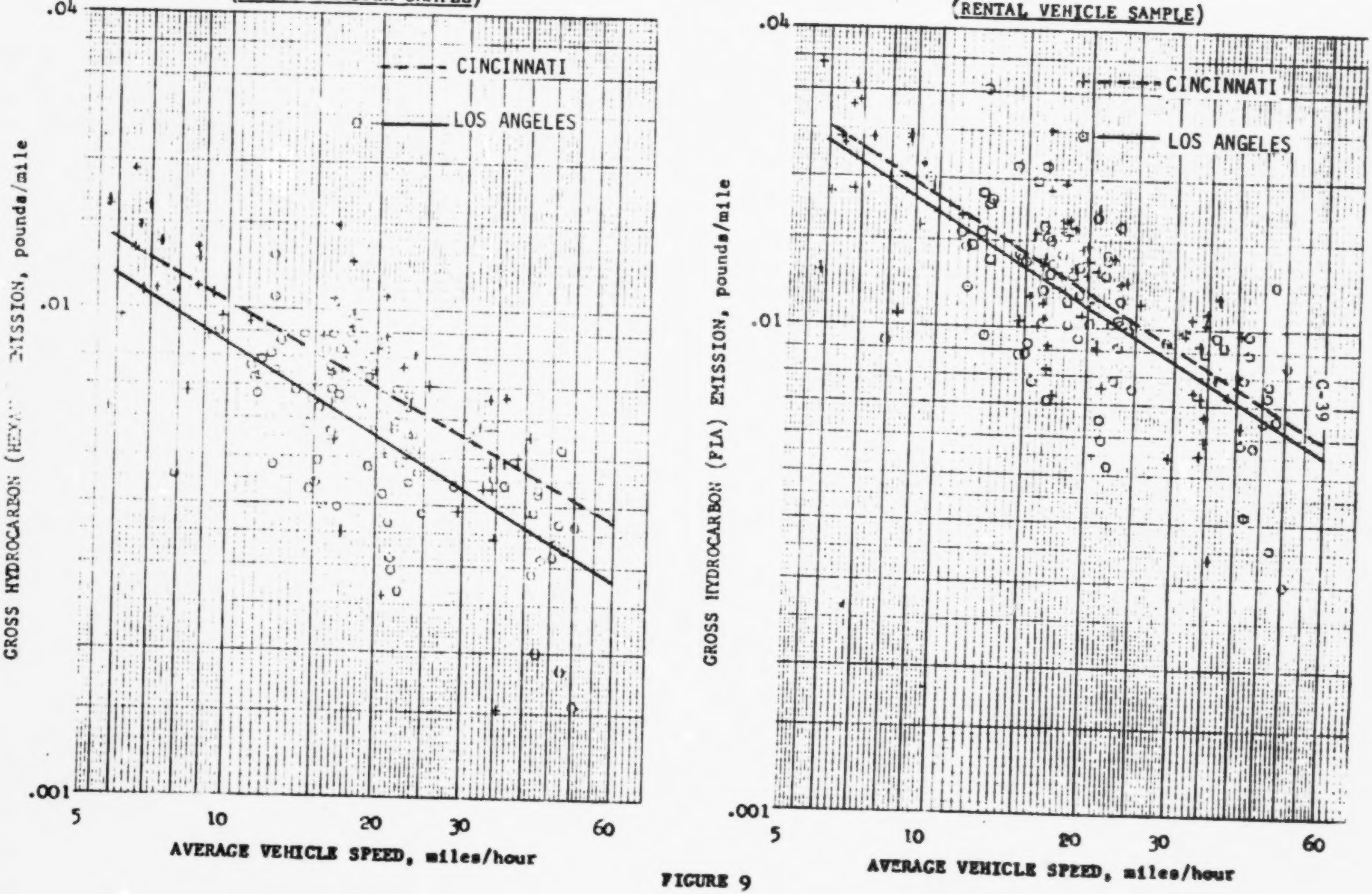
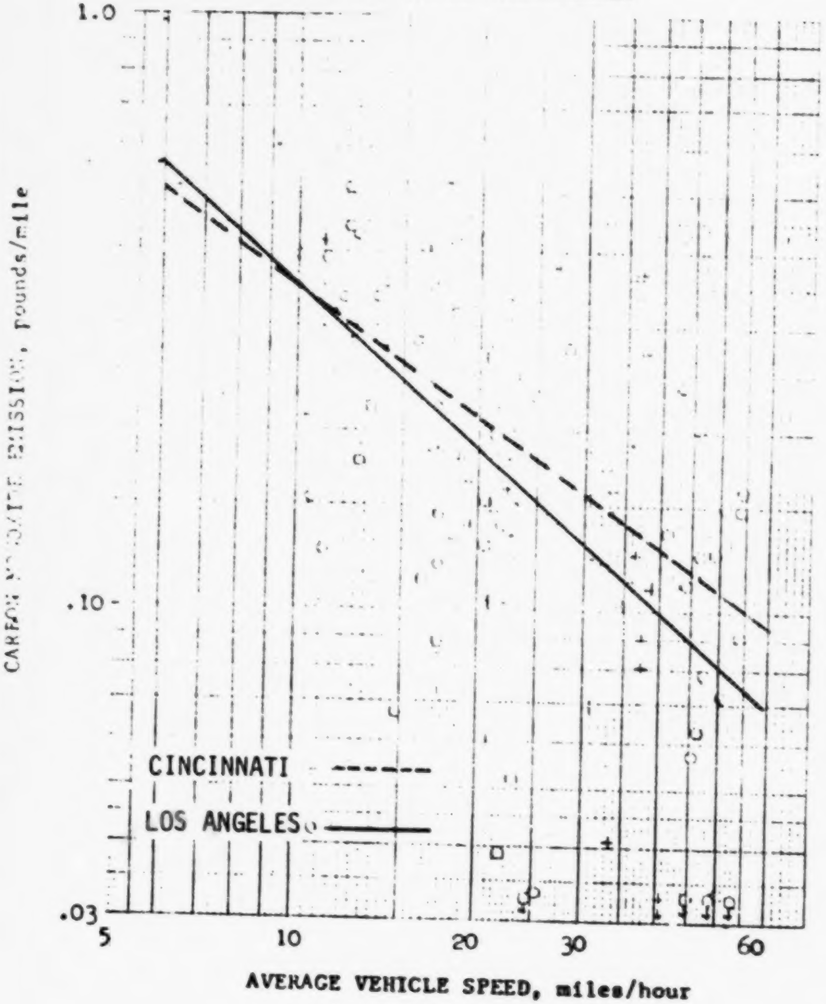


FIGURE 9

POUNDS OF CARBON MONOXIDE
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RANDOM VEHICLE SAMPLE)



POUNDS OF CARBON DIOXIDE
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(RANDOM VEHICLE SAMPLE)

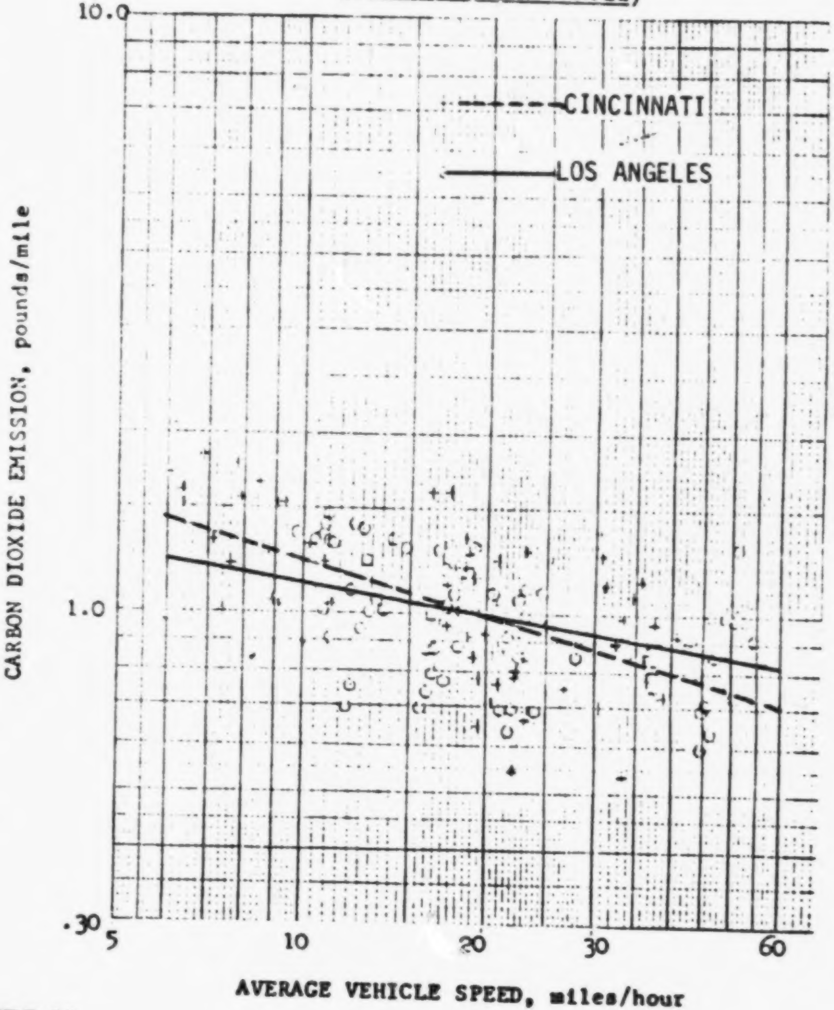
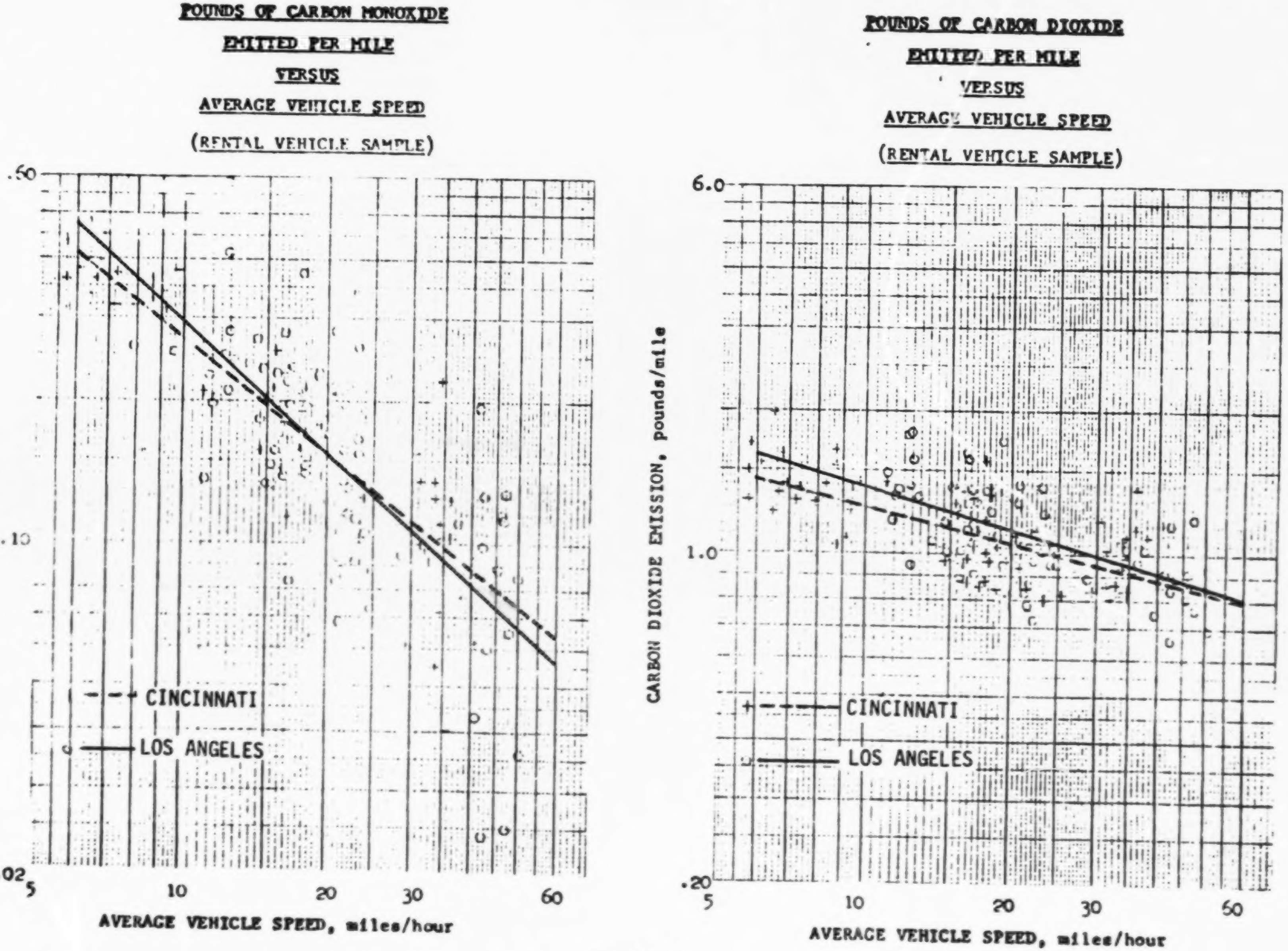


FIGURE 10



POUNDS OF CARBON MONOXIDE EMITTED PER MILE VERSUS AVERAGE VEHICLE SPEED (RENTAL VEHICLE SAMPLE)

POUNDS OF CARBON DIOXIDE EMITTED PER MILE VERSUS AVERAGE VEHICLE SPEED (RENTAL VEHICLE SAMPLE)

FIGURE 11

POUNDS OF OXIDES OF NITROGEN EMITTED
VERSUS
AIR-FUEL RATIO
(RANDOM VEHICLE SAMPLE)

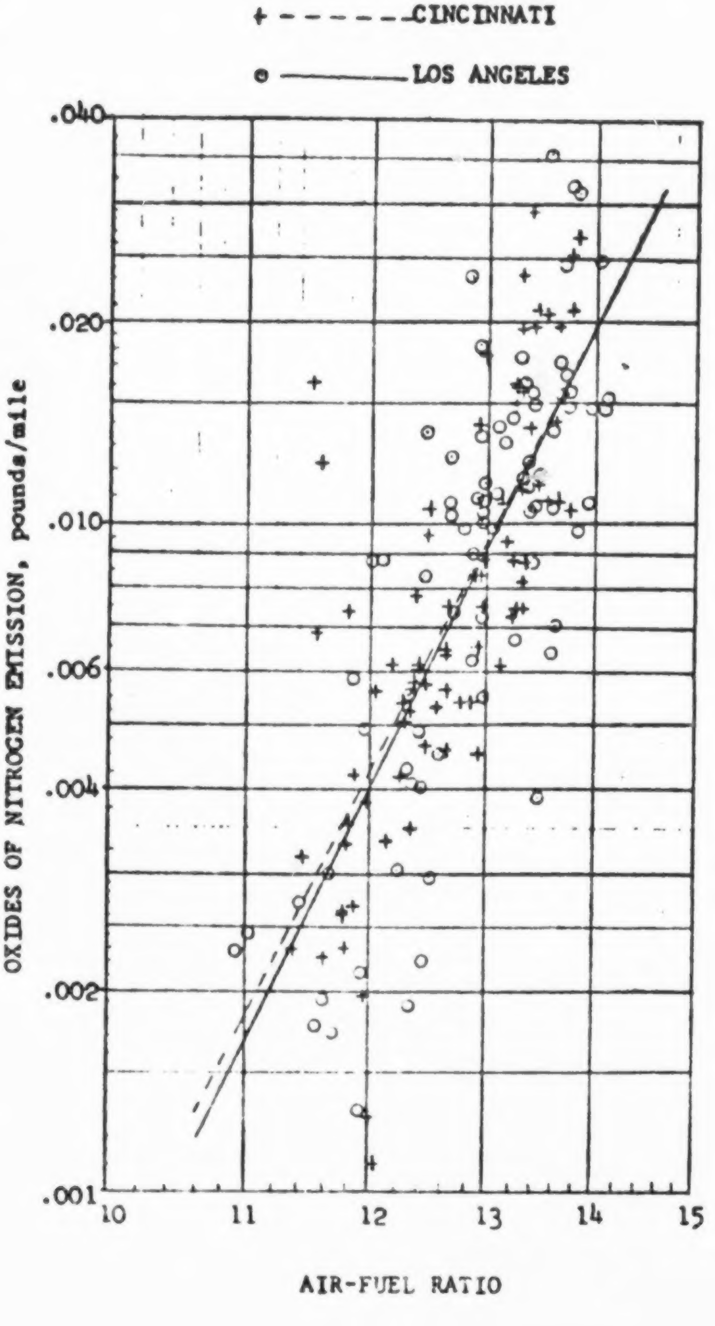


FIGURE 12

POUNDS OF OXIDES OF NITROGEN EMITTED
VERSUS
AIR-FUEL RATIO
(RENTAL VEHICLE SAMPLE)

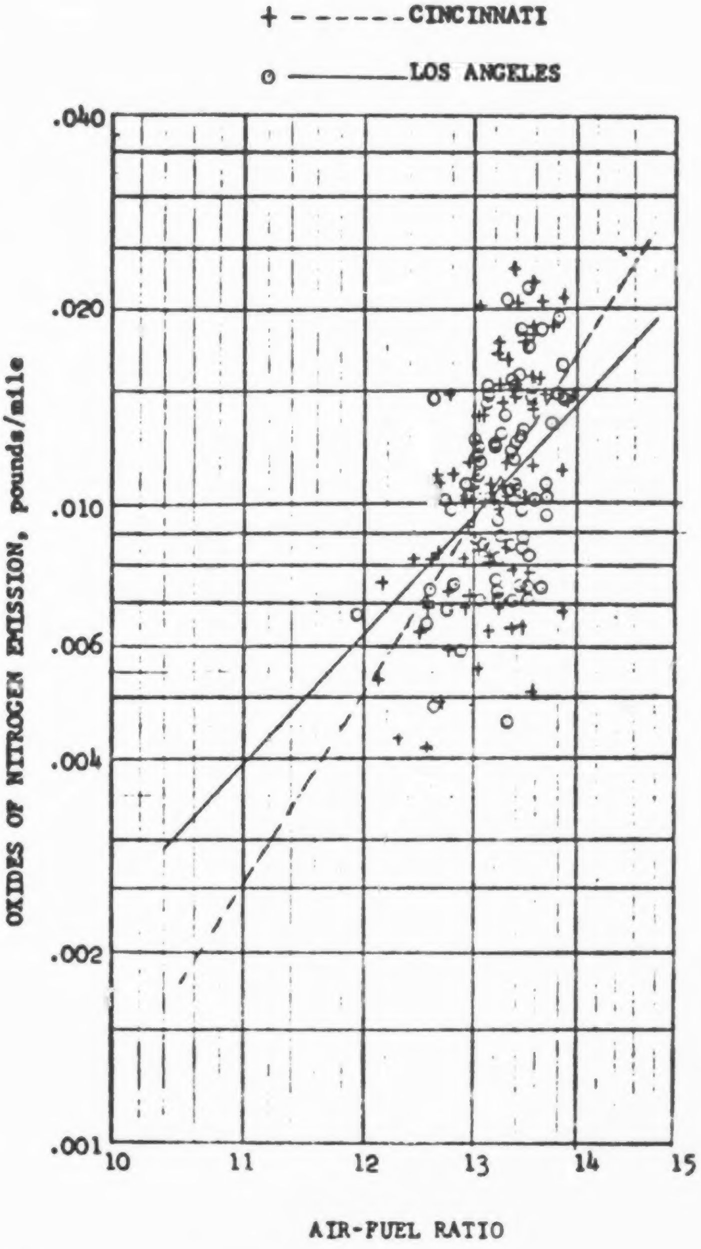


FIGURE 13

POUNDS OF GROSS HYDROCARBON (HEXANE)
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(LOS ANGELES RANDOM VEHICLE SAMPLE)

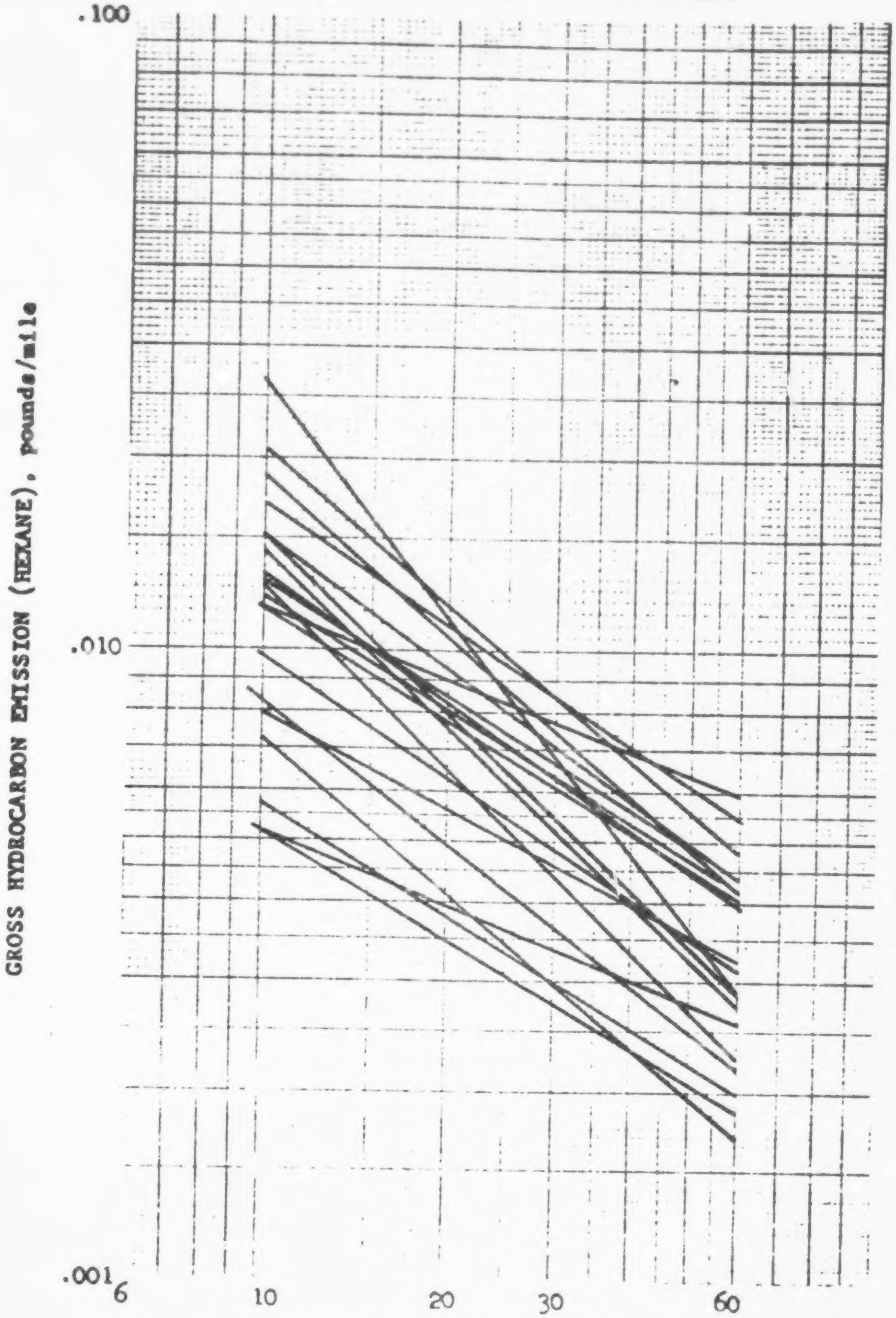
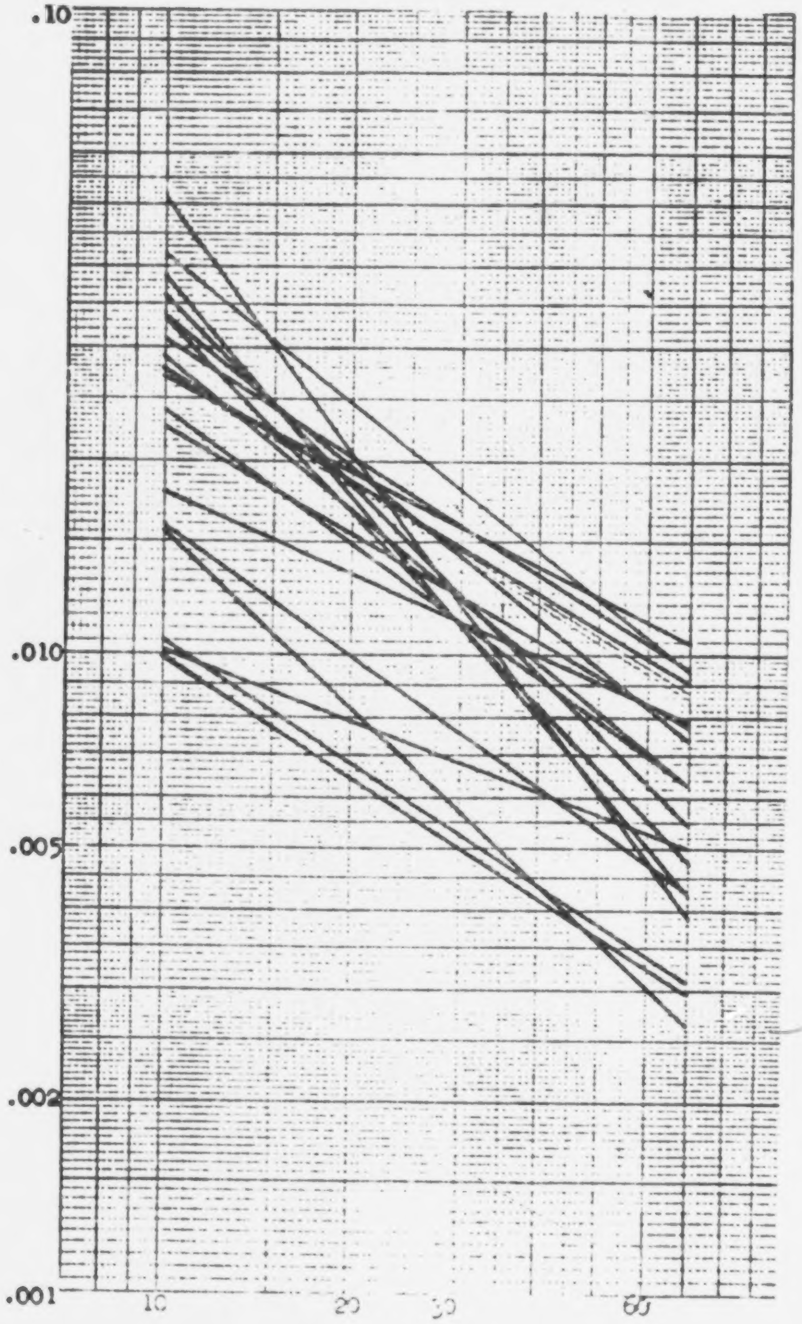


FIGURE 14

POUNDS OF GROSS HYDROCARBONS (FIA)
EMITTED PER MILE
VERSUS
AVERAGE VEHICLE SPEED
(LOS ANGELES RANDOM VEHICLE SAMPLE)



AVERAGE VEHICLE SPEED, miles/hour

FIGURE 15

POUNDS OF CARBON MONOXIDE EMITTED PER MILE

VERSUS

AVERAGE VEHICLE SPEED

(LOS ANGELES RANDOM VEHICLE SAMPLE)

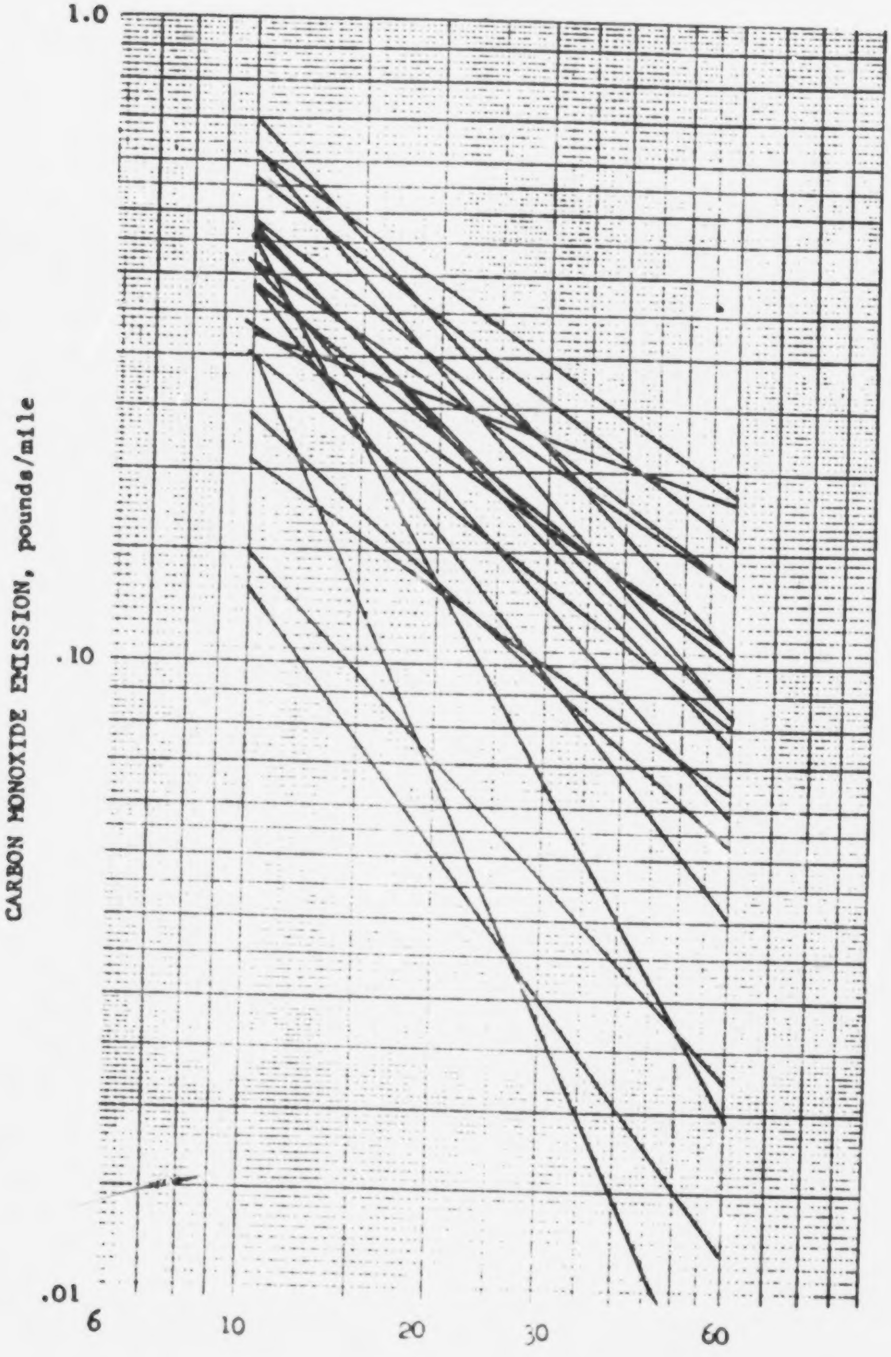


FIGURE 16

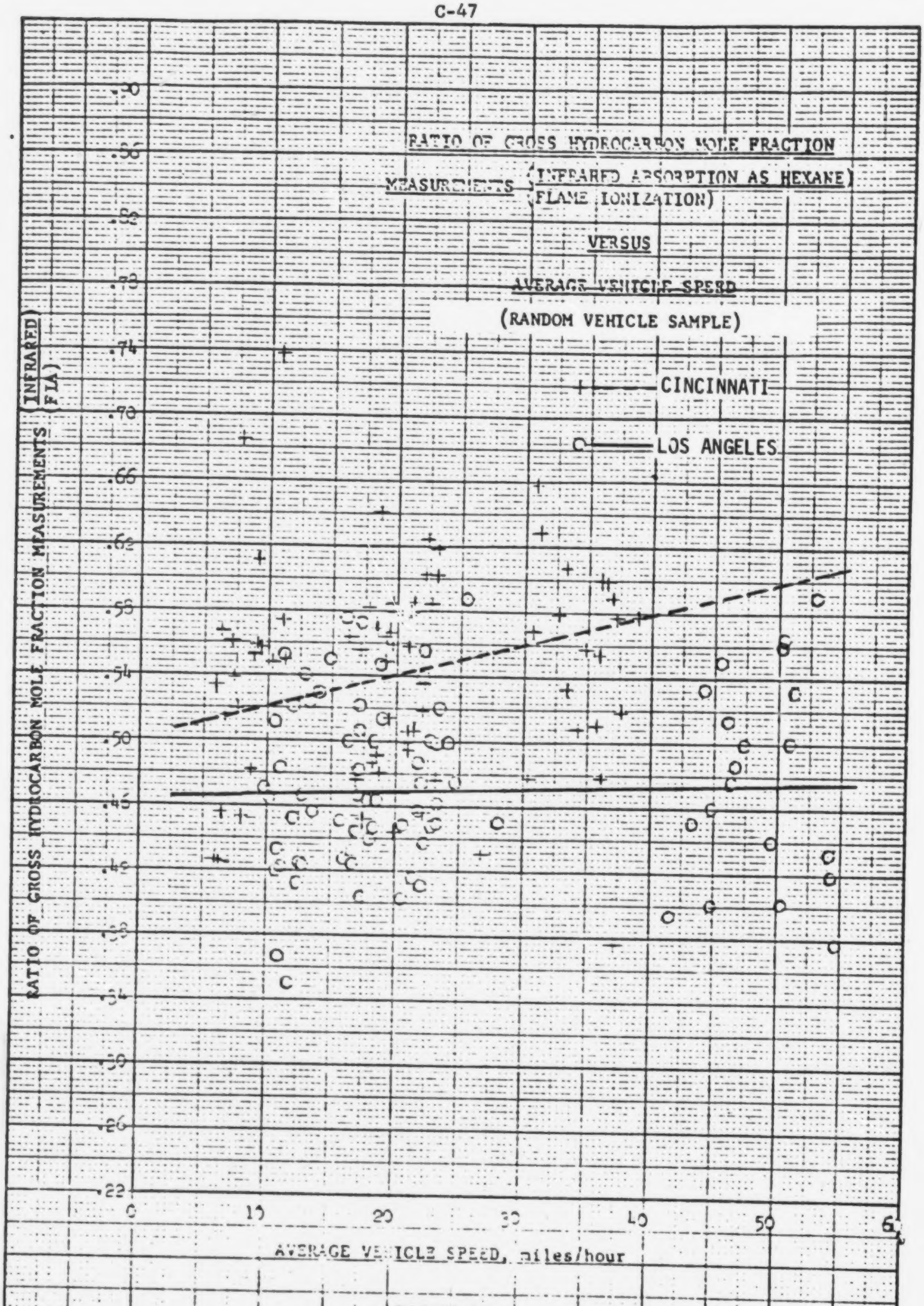

RATIO OF GROSS HYDROCARBON MOLE FRACTION
MEASUREMENTS (INFRARED ABSORPTION AS HEXANE) / (FLAME IONIZATION)
VERSUS
AVERAGE VEHICLE SPEED
(RANDOM VEHICLE SAMPLE)
+ CINCINNATI
O LOS ANGELES
RATIO OF GROSS HYDROCARBON MOLE FRACTION MEASUREMENTS (INFRARED) / (FIA)
.90
.86
.82
.78
.74
.70
.66
.62
.58
.54
.50
.46
.42
.38
.34
.30
.26
.22
0
10
20
30
40
50
60
AVERAGE VEHICLE SPEED, miles/hour

FIGURE 17

APPENDIX D

ESTIMATING EMISSION REDUCTIONS FROM TRAFFIC FLOW TECHNIQUES

As indicated in the previous appendix, motor vehicle exhaust emissions (carbon monoxide) are lower in freely-flowing traffic than in congested, stop-and-go conditions. Hence, traffic flow improvements can result in reduced emissions. These improvements, however, also tend to increase roadway carrying capacity at the same time. Consequently, in estimating the emission reductions from traffic flow improvements one must consider both the average per vehicle emissions (which may be lower as a result of improved flows and higher average speeds) and the volume of vehicles using the roadway (which may be higher as a result of greater roadway capacity).

In the latter connection, consideration is required of three factors: (1) the increase in roadway capacity that results from traffic flow improvements; (2) the rate at which increased capacity is utilized (bearing in mind that traffic flow improvements tend to generate additional trips that otherwise would not have been made); and (3) the net emission trade-off over time between potentially higher speeds and potentially higher volumes along a given roadway following traffic flow improvements. Each of these factors is discussed below.[1]

---

[1] Primary attention in the following discussion is on peak-hour capacity. It is not particularly meaningful to use maximum daily capacity as a measure since one peak hour may account for more than 10 percent of total daily travel. Conversely, almost no trips may be made during other hours (e.g., between midnight and dawn).

Increase in Roadway Capacity

Determining the increase in roadway capacity following traffic flow improvements requires knowledge of speed-volume relationships in urban areas. Because of relatively high traffic volumes and low speeds characteristic of central business district (CBD) streets, this area is likely to show the greatest potential for emission reductions from traffic flow improvements. Unfortunately, typical speed-volume relationships used on urban arterials and rural roads have not been developed for downtown streets; major difficulties have been encountered in attempting to develop speed and volume measurements because of differences in the functions and services of CBD streets.[1] Since available data do not permit an estimate of speed and volume changes from traffic flow improvements on CBD streets, we must draw from recognized data and relationships which have been developed for urban arterials.[2]

---

[1] As the *Highway Capacity Manual* notes:

> It is not yet feasible to develop charts or curves presenting basic speed-volume relationships for extended sections of downtown streets ... *At present, with the current limited knowledge of the complex relationships which govern downtown traffic flow, it is not possible to develop even typical speed-v/c* [volume to capacity] *ratio relationships*. The capacities of apparently similar downtown streets vary widely due to differing environmental [local traffic frictions, street geometry, etc.] conditions.

Highway Research Board, *Highway Capacity Manual*, Special Report 87 (Washington, D.C.: National Academy of Sciences-National Academy of Engineering, 1966), p. 332. (Emphasis added.)

[2] Though the examples do not employ data from any specific city, they are based upon observations and relationships which have been verified over a relatively long period of time in a number of urban areas. Consequently, the conclusions appear generally valid for most cities. Urban arterials are defined in the *Highway Capacity Manual* as "... major streets and highways outside the central business district having either (1) intersection signalization at an average spacing of one mile or less, or (2) speed limits of 35 mph or less due to extensive roadside development." *Ibid.*, p. 318.

The illustrations which follow do not necessarily reflect CBD street conditions, but they do represent the only data presently available for any form of urban street.[1]

Rate of Increased Capacity Utilization

As explained in Chapter 3, traffic growth can be considered to consist of two components: (1) long-term or trend growth and (2) "induced" or "generated" growth (i.e., the attraction of new trip-makers because of new capacity or improved conditions). To some extent, long-term traffic growth results from factors different from those which stimulate "induced" growth (e.g., growth in incomes may stimulate long-term trip-making while traffic flow improvements may stimulate "induced" growth). However, both growth rates reflect to some degree the extent to which existing roadway capacity is at "saturation."

Because all these factors interact and their dynamics are imperfectly understood, we have had to make a variety of assumptions about traffic growth to illustrate the effects of increased volume on speed (and subsequently on emissions) for typical urban arterials. Under assumptions for Case 1, no traffic flow techniques are implemented. Consequently, no induced traffic is assumed, only trend growth at 3 percent per annum. Case 2 includes an identical trend rate and an induced traffic stream anticipated to utilize (by the end of year 2) the capacity increase made possible by traffic flow improvements. In Case 3, the same assumptions are made as in Case 2 with respect to induced traffic, but the rate of trend growth is anticipated to decline as roadway capacity approaches saturation. Table D-1 illustrates, for each of the three cases, the impacts on speed and volume over a five-year horizon following implementation of traffic flow techniques in Year 1.

---

[1] In deriving the speed and volume factors used in the illustrations below, Table 10.13 and Figure 10.3, Curves II and III from the Highway Research Board, Highway Capacity Manual, Special Report 87 (Washington, D.C.: National Academy of Sciences-National Academy of Engineering, 1966), were used. These curves show levels of service along with overall average travel speeds and volume-to-capacity ratios for urban arterials.

Impacts on speed and volume result from a "package" of traffic flow techniques (assumed to consist largely of improved signalization) on a typical urban arterial. Roadway capacity in the base year (i.e., prior to any improvements) is assumed to be approximately 1,500 vehicles per hour per lane for one-way direction, and the average vehicle speed is assumed to be 15 miles per hour. Traffic flow techniques are assumed to be implemented in year 1, at which time speed increases 5 miles per hour. Increased vehicle speeds from implementation of traffic flow techniques are felt in year 1, although the induced traffic generated by these improvements is not assumed to occur until year 2. This assumption about induced traffic is probably conservative, since in most cities drivers respond rather rapidly to traffic improvements.

Table D-1

ILLUSTRATIVE IMPACTS OF TRAFFIC FLOW TECHNIQUES ON SPEED AND VOLUME[1]

Factors	Base Year	Year 1	Year 2	Year 3	Year 4	Year 5	Source
Case 1: Trend 3%/Induced None/No Traffic Flow Techniques							
1. Capacity (vph/lane/one way)	1500	1500	1500	1500	1500	1500	Assumed
2. Trend Volume (3% p.a.)	1500	1545	1591	1639	1688	1739	Assumed
3. Induced Volume (0)	0	0	0	0	0	0	Assumed
4. Total Volume	1500	1545	1591	1639	1688	1739	Line 2 + Line 3
5. Volume to Capacity Ratio	1.00	1.03	1.06	1.09	1.13	1.16	Line 4 ÷ Line 1
6. Speed (mph)	15	14	13	12	11	10	Interpolation[2]
Case 2: Trend 3%/Induced Two Years to Capacity/Traffic Flow Techniques in Year 1							
7. Capacity (vph/lane/one way)	1500	1750	1750	1750	1750	1750	Assumed
8. Trend Volume (3% p.a.)	1500	1545	1591	1639	1688	1739	Assumed
9. Induced Volume	0	0	159	250	250	250	Assumed
10. Total Volume	1500	1545	1750	1889	1938	1989	Line 8 + Line 9
11. Volume to Capacity Ratio	1.00	.88	1.00	1.08	1.11	1.14	Line 10 ÷ Line 7
12. Speed (mph)	15	20	15	13	12	10	Interpolation[2]
Case 3: Trend 3% - 2% - 1.5%/Induced Two Years to Capacity/Traffic Flow Techniques in Year 1							
13. Capacity (vph/lane/one way)	1500	1750	1750	1750	1750	1750	Assumed
14. Trend Volume (3%-2%-1.5% p.a.)	1500	1545	1591	1623	1647	1672	Assumed
15. Induced Volume	0	0	159	250	250	250	Assumed
16. Total Volume	1500	1545	1750	1873	1897	1922	Line 14 + Line 15
17. Volume to Capacity Ratio	1.00	.88	1.00	1.07	1.08	1.10	Line 16 ÷ Line 13
18. Speed (mph)	15	20	15	14	13	11	Interpolation[2]

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[1] Traffic flow techniques implemented on an urban arterial and assumed to consist primarily of improved signalization, as explained in text.

[2] From Highway Capacity Manual, 1965, as explained in text.

Net Emission Tradeoff

Having obtained the speed-volume levels following implementation of traffic flow techniques, we can now calculate the resulting emissions.[1] Table D-2 summarizes the impacts of implementing traffic flow techniques on emissions over a five-year period. As indicated for Cases 2 and 3 involving traffic flow techniques, absolute emissions decrease for only the year immediately following implementation, when emissions will be some 17.6 percent less than the base year. For air pollution control purposes, however, a more meaningful comparison of these two cases would be with Case 1 (i.e., emissions on a roadway segment where no traffic flow techniques have been implemented). Using this relative measure, Table D-2 shows that emissions along the arterial in Cases 2 and 3 would be less in year 2 than the resulting emissions if no improvements were made. For all subsequent years, emission levels would be higher than if no traffic flow techniques were implemented at all. In year 5, for example, emissions would be approximately 24 percent greater for Case 2 than for Case 1 and 19 percent greater for Case 3.

The reasons for this increase in relative emissions following year 2 can be readily ascertained from Table D-2. Although speeds following traffic flow improvements in Cases 2 and 3 are always higher than

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[1] The estimates which follow are based on preliminary EPA data on carbon monoxide emissions as a function of speed for pre-controlled vehicles, as explained in Appendix C. See M. J. McGraw and R. L. Duprey, "Compilation of Air Pollutant Emission Factors," Preliminary Document Environmental Protection Agency, April 1971. (Mimeographed.) Consequently, application of these data to present in-use vehicles is somewhat speculative. However, the substitution of any similar speed-emission relationship for the above-cited one should not substantially alter our basic conclusions.

Table D-2

ILLUSTRATIVE IMPACT OF TRAFFIC FLOW TECHNIQUES ON EMISSIONS

Factors	Base Year	Year 1	Year 2	Year 3	Year 4	Year 5	Source
Case 1: Trend 3%/Induced None/ No Traffic Flow Tehniques							
1. Volume (vph/lane/one way)	1500	1545	1591	1639	1688	1739	Table D-1, Line 4
2. Volume Increase over Base Year (%)		3	6	9	13	16	
3. Speed (mph)	15	14	13	12	11	10	Table D-1, Line 6 McGraw, Duprey[1]
4. Emission Factor	1.00	1.10	1.17	1.23	1.33	1.43	
5. Change in Emission Factor over Base Year (%)		10	17	23	33	43	
6. Net Emissions Tradeoff (%)		13	24	34	50	66	$\frac{(\text{Line 1} \times \text{Line 4})-1500}{1500 \times 1.00}$
Case 2: Trend 3%/Induced Two Years to Capacity/Traffic Flow Techniques in Year 1							
7. Volume (vph/lane/one way)	1500	1545	1750	1889	1938	1989	Table D-1, Line 10
8. Volume Increase over Base Year (%)		3	17	26	29	33	
9. Speed (mph)	15	20	15	13	12	10	Table D-1, Line 12 McGraw, Duprey[1]
10. Emission Factor	1.00	.80	1.00	1.17	1.23	1.43	
11. Change in Emission Factor over Base Year (%)		-20	0	17	23	43	
12. Net Emission Tradeoff (%)		-18	17	49	59	90	$\frac{(\text{Line 7} \times \text{Line 10})-1500}{1500 \times 1.00}$
Case 3: Trend 3% - 2% - 1.5%/Induced Two Years to Capacity/Traffic Flow Techniques in Year 1							
13. Volume (vph/lane/one way)	1500	1545	1750	1873	1897	1922	Table D-1, Line 16
14. Volume Increase over Base Year (%)		3	17	25	27	28	
15. Speed (mph)	15	20	15	14	13	11	Table D-1, Line 18 McGraw, Duprey[1]
16. Emission Factor	1.00	.80	1.00	1.10	1.17	1.33	
17. Change in Emission Factor over Base Year (%)		-20	0	10	17	33	
18. Net Emission Tradeoff (%)		-18	17	37	48	70	$\frac{(\text{Line 13} \times \text{Line 16})-1500}{1500 \times 1.00}$

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[1] EPA data as explained in text, but with emission factor in base year at 15 miles per hour adjusted to equal 1.00.

for Case 1 (with one exception where it is identical), the relative reduction in per vehicle emission factors associated with the higher speeds becomes rapidly overwhelmed by the additional number of vehicles using the arterial. Thus, for Case 2, although the higher average speed in year 4 (12 miles per hour as compared to 11 miles per hour for Case 1) results in 10 percent relative reduction in the emission factor (from 1.33 to 1.23), relative traffic volume increases approximately 16 percent (from 29.2 to 12.5) -- a resultant 8.9 percent (from 58.9 to 50.0) relative increase in emissions. These examples show the rapidity with which emission reductions from traffic flow improvements are overwhelmed by increased vehicular volumes,[1] and that, even over a short-term of three to five years, relative emissions can be considerably greater than if no improvements were made at all.

Consequently, as indicated in Chapter 3, traffic flow improvements should be viewed only as extremely short-term measures, unless traffic volumes can be reduced or restrained. For example, if motor vehicle restraints could prevent substantial increases in traffic volumes, potential emission reductions could be considerable. To illustrate this point an additional example has been developed.

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[1] The rapidity with which emission reductions are offset by higher vehicle volumes is, as explained above, a function of the assumptions made about the traffic generation process (as well as the initial volume to capacity ratio of the arterial). Variations in these factors will alter the time dimension to some extent, but will not alter the basic dynamics.

Reducing Traffic Volumes with Motor Vehicle Restraints

In Case 4, we assume that a motor vehicle restraint program (consisting of doubling parking prices and reducing significantly on-street parking) is implemented, and further that this program results in a 20 percent decline in vehicle miles traveled.[1] Trend growth is assumed to continue at a rate of about 3 percent in year 1, but then decline to about 2 percent as a result of the restraint, while induced trips would increase from 10 to 16 percent as drivers adjust to changes in parking prices and as parking price increases are passed on to consumers. Table D-3 summarizes these assumptions and illustrates the impacts of a motor vehicle restraint program on vehicle speeds and volume.[2]

Table D-4 indicates the resulting net emissions trade-off. As shown the absolute emissions decrease for each of the five years following implementation of a motor vehicle restraint program. When viewed relative to Case 1 (i.e., no action taken), emission reductions are even more substantial, ranging from approximately 56 percent fewer emissions in year 1 through 3 to 74 percent fewer emissions in year 5. Thus, motor vehicle restraints capable of reducing traffic volumes on an urban arterial could have a substantial impact in reducing motor vehicle emissions.

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1. For further discussion, see Appendix F, "Estimating Emission Reductions from Motor Vehicle Restraints."

2. Conceivably, emission reductions could be significantly greater with motor vehicle restraints and traffic flow techniques, although the incremental value of the latter is difficult to determine without computer simulation.

Table D-3

ILLUSTRATIVE IMPACTS OF TRAFFIC FLOW TECHNIQUES AND MOTOR VEHICLE RESTRAINTS ON SPEED AND VOLUME

Factors	Base Year	Year 1	Year 2	Year 3	Year 4	Year 5	Source
Case 4: Double Price of Parking for 20% Vehicle Reduction/Trend 3% and 2 Induced 10-16% of Trend & Restraint Volumes							
1. Capacity (vph/lane/one way)	1500	1750	1750	1750	1750	1750	Assumed
2. Trend Volume (Year 1 3%/ 2% after)	1500	1545	1576	1608	1640	1673	Assumed
3. Restraint (-20% of Base Year)		-300	-300	-300	-300	-300	20% of 1500
4. Total	1500	1245	1276	1308	1340	1373	Lines 2 + 3
5. Induced Volume (10-12-14-16%)		0	128	157	188	220	Line 4 x (10-16%)
6. Total	1500	1245	1404	1465	1528	1593	Line 4 + Line 5
7. Volume to Capacity Ratio	1.00	.71	.80	.84	.87	.91	Line 6 ÷ Line 1
8. Speed (mph)	15	25	23	21	20	19	Interpolation[1]

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[1] From Highway Capacity Manual, 1965, as explained in text.

Table D-4

ILLUSTRATIVE IMPACT OF TRAFFIC FLOW TECHNIQUES AND MOTOR VEHICLE RESTRAINTS ON EMISSIONS

Factors	Base Year	Year 1	Year 2	Year 3	Year 4	Year 5	Source
Case 4: Double Price of Parking for 20% Vehicle Reduction/Trend 3% and 2%/ Induced 10-16% of Trend & Restraint Volumes							
1. Volume (vph/lane/one way)	1500	1245	1404	1465	1528	1593	Table D-3, Line 6
2. Volume Increase over Base Year (%)		-17	-6	-2	2	6	
3. Speed (mph)	15	25	23	21	20	19	Table D-3, Line 8
4. Emission Factors	1.00	.67	.73	.80	.83	.87	McGraw, Duprey[1]
5. Change in Emission Factors over Base Year (%)		-33	-27	-20	-17	-13	
6. Net Emissions Tradeoff (%)		-44	-32	-22	-15	-8	$\frac{(\text{Line 1 x Line 4})-1500}{1500 \text{ x } 1.00}$

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1. EPA data as explained in text, but with emission factor in base year at 15 miles per hour adjusted to equal 1.00.

APPENDIX E

ESTIMATING EMISSION REDUCTIONS FROM PUBLIC TRANSPORT IMPROVEMENTS

As indicated in Chapter 5, public transport improvements alone hold out little promise for major modal diversions, much less a reduction in motor vehicle emissions. Our best judgment is that even extensive improvements would be unlikely to reduce vehicle miles traveled[1] (and hence emissions) by more than 5 percent in any major metropolitan area.

For a number of reasons (see below), the Philadelphia Lindenwold Rapid Transit line probably represents the best commuter rail service this country has to offer. Accordingly, the Lindenwold line provides a good indication of the maximum feasible emission reductions which would be possible from public transport improvements.

In the following we indicate how the Lindenwold line has combined speed, convenience and comfort at a moderate cost with an agressively marketed transit service aimed at meeting the competition of the automobile. We conclude, however, that although the line has obviously made its mark on improving suburban rapid rail service, its impact on reducing motor vehicle traffic (and concomitant emissions) is less evident and more difficult to measure. A reduction in motor vehicle traffic directly attributable to the Lindenwold line has not occurred, at least as reflected in available data.

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[1] Reference is particularly to vehicle miles traveled by light duty motor vehicles (e.g., the private passenger car).

The Philadelphia-Lindenwold Rapid Transit Line

Since February 1969, the Philadelphia-Lindenwold line has provided high speed access to the commercial centers of Camden and Philadelphia for commuters from the densely populated suburbs in South New Jersey.[1] This construction of a new rail rapid system (accomplished in three years at a total cost of $92 million) offered an opportunity to include a package of new design and operational features not so completely available in other U.S.transit systems. The operating agency, the Port Authority Transit Corporation (PATCO), a wholly-owned subsidiary of the Delaware River Port Authority,[2] maintains an attitude of concern for customer satisfaction. For these reasons, the Philadelphia-Lindenwold line probably represents the best commuter rail service the country has to offer. Speed, convenience and comfort at a moderate cost have been merged into an aggressively and successfully marketed transit service.

During peak hours, a train appears every four minutes. During off-peak periods, service is provided at least every 10 minutes. There never is a last train to catch; service continues around the clock. The present one-way maximum 60¢ fare[1] and the 22-minute ride[2] (over a 14.5 mile line) makes the service highly competitive with automobile time and cost. The average 40 mph speed (maximum speed reached is 75 mph) betters the 30-35 mph on adjacent highways. The automobile cost (out-of-pocket) for the trip in 1970 totaled $2.80, including parking and tolls.[3]

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[1] The 14.5 mile line extends from Lindenwold, N.J., to Camden over the Ben Franklin Bridge to Philadelphia.

[2] The Delaware River Port Authority (DRPA) utilizing bridge toll profits from two Delaware River crossings, as well as new bond issues, financed and constructed the new line. This diversion of funds from automobile traffic to the construction of a mass transit facility represents one of the first such occurrences in the country.

The fully automated service includes fare collection and train operation. Automatic ticket vending machines provide passengers with tickets that electronic sensors scan at station gates which allow entry and exit. At the exit gate, sensors verify the ticket's destination with the exiting station, deduct a trip from multiple ride passes, or capture one-trip tickets. Stations are unattended but under television monitoring from central control. Passengers having difficulty negotiating station gates are automatically directed to a special telephone for communication with central control.

Television surveillance at all 12 stations is also maintained for security purposes. A public address system is also available to the TV monitor for each and every station and platform.

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[1] This maximum 60¢ one-way fare (which has been maintained for three years) compares with a $1.20 fare in 1970 on the Long Island Railroad for the same distance but certainly not the same service. PATCO made application to the ICC for a 22 percent fare increase with a ruling expected by March 1972.

[2] Express trains make the trip in 19 minutes.

[3] Tolls on the two Delaware bridges between Philadelphia and New Jersey (the Ben Franklin and Walt Whitman Bridges) were increased in mid-1968 from 25¢ to 50¢ for single rides. Commutation tickets increased from 20¢ to 25¢.

One attendant rides each train to open and close train doors. Otherwise, the train's progress is under automatic train control which programs its speed, acceleration and deceleration through WABCO continuous coded cab signals. If an emergency dictates, trains can be operated manually.

Seventy-five new air-conditioned stainless steel cars are designed for passenger comfort with an unusually high ratio of seats (80) to standing capacity (40). Seats are wide, high-backed, and designed for long distance riding. Attractive station interiors are also climate-controlled (heated and air-conditioned). Convenient access is provided, with station location at major road connections and intersections and the availability of 8,900 station parking spaces, some free. Schedules are adhered to with a customary 99 percent rating for on-time performance. Graffiti disappear when stations are cleaned six nights weekly. Trains are swept nightly and thoroughly cleaned twice weekly. In short, all aspects of the line's design and operation have been directed toward consumer acceptance and meeting the competition of the automobile.

Public response to the new Philadelphia-Lindenwold service was immediate acceptance. Initially, daily volumes of 12,000 to 15,000 riders were expected. Yet, the average daily ridership in the first week of operation was 16,200, with 17,300 in the second week. A steady increase has resulted in a daily ridership of about 36,000 passengers in February 1972. Table E-1 summarizes monthly patronage for all stations since the inception of service in January 1969. Based on existing trends, passenger volumes may be expected to range between 800,000 and 900,000 a month by the end of 1972. However, the data also suggest some stabilization of passenger volumes at these levels.

Table E-1

PHILADELPHIA-LINDENWOLD RAPID TRANSIT
Monthly Patronage-Passengers
January 4, 1969 - September 1971

Month	1969	1970	1971
January	84,031	689,959	757,844
February	226,968	634,173	721,001
March	477,966	711,000	805,419
April	507,026	720,958	773,041
May	522,728	679,180	738,017
June	535,650	706,064	780,191
July	555,273	706,750	729,038
August	556,930	687,321	757,394
September	605,311	725,862	786,240
October	684,640	794,005	---
November	626,092	757,277	---
December	722,943	843,540	---

Source: Port Authority Transit Corporation of Pennsylvania and New Jersey, Camden, New Jersey.

Despite the growth in patronage, the forecast ridership has not been achieved.[1] A consultant's projected annual volumes of 11.1, 16.2, and 16.9 million for 1969, 1970, and 1971,[2] respectively, did not materialize. Table E-2 compares the consultant's average weekday forecast for individual stations with actual experiences and confirms the gap between forecast traffic and experience. However, actual annual volumes have been increasing at 6.1, 8.6, and 9.4 million for the same years and the ridership for 1972 is expected to be about 10 million.

As might be expected, the line has not proved to be the moneymaker or break-even operation that was anticipated (although the automated operation was specifically directed to eliminate many labor intensive costs of rail operation). However, the deficit operation has practically disappeared. Out-of-pocket operating losses of $700,000 in 1969 and $147,000 in 1970 were drastically reduced to only $6,722 in 1971.[3]

Lack of a feeder bus service has been blamed for this inability to achieve anticipated growth. However, the Trenton-Philadelphia Coach Company which has been servicing the Haddonfield station since September 1971 only carries 100 passengers each way daily. Some observers believe that

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[1] The consultant (using 1960 data) assumed continuing economic activity, and did not foresee later economic downturns. The Camden area in particular has been severely depressed economically. Expansion that was predicted for certain business activities did not occur and thus a projected heavy eastbound traffic between Philadelphia and Camden never developed.

It is also believed that public fear about increasing crime and vandalism in the CBD has reduced public transit trips. Fare increases on connecting lines of SEPTA and feeder bus services (also assumed by the consultant) which were not initiated probably further reduced ridership potential.

[2] Telephone communication with J. W. Vigrass, Supervisor, Traffic and Planning, Port Authority Transit Corporation, Camden, New Jersey, February 14, 1971.

[3] Ibid.

Table E-2

PHILADELPHIA-LINDENWOLD RAPID TRANSIT LINE
Forecast versus Actual Traffic
Average Week-day
Entering Passengers

Station	Consultant's Forecast[1]	Actual Week-day Average Week Ending 9/17/71	Percent of Forecast
Lindenwold	3,220	4,069	126.4[2]
Ashland	1,240	2,307	186.0[2]
Haddonfield	6,425	2,997	46.6[3]
Westmont	2,575	2,041	79.3
Collingswood	4,225	1,834	43.4[3]
Ferry Ave.-Camden	2,950	2,739	92.8[3,4]
Broadway - Camden	7,345	1,567	21.3[4]
City Hall -Camden	3,170	2,572	81.1[4]
8th-Market-Phila.	14,585	6,408	43.9[5]
9-10-Locust	1,025	600	58.5
12-13-Locust	3,960	2,437	61.5
15-16-Locust	3,010	5,608	186.3[6]
Total	53,730	35,177	65.5

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1. Consultant's forecast prepared in late 1968 subject to limitations noted in text.

2. Additional parking space provided after start of operation.
3. Feeder bus services not operating. No coordination between buses and PATCO.
4. Two major firms in Camden shut down, eliminating more than 6,000 jobs.
5. Due to SEPTA higher connecting fares and public fear of shopping in CBD, this station has not matched estimated traffic.
6. Area experiencing major office building construction and improved shopping area.

Source: Port Authority Transit Corporation of Pennsylvania and New Jersey, Camden, New Jersey.

conventional bus services can never be successful in an area as sparsely populated as that adjacent to the Haddonfield and other stations. On February 19, 1972 the long awaited demand-actuated bus demonstration service was inaugurated at the Haddonfield station. The New Jersey State Department of Transportation and the Urban Mass Transportation Administration are jointly funding this demonstration which will provide door-to-door service for commuters to the Lindenwold line. Another proposed feeder service at four stations would engage a private bus operator under a service contract to the State Department of Transportation. This proposed service is awaiting the Governor's approval. The implications, for commuter rail service nationwide, of establishing such a precedent arrangement, will probably delay this approval until detailed study has been completed.

Although forecasts have not been realized, optimism prevails. The Delaware River Port Authority is seriously studying an extended three-prong system initially proposed by its consultants 15 years ago. These plans would more than triple the present track mileage. In 1971, the New Jersey Legislature endorsed the Philadelphia-Lindenwold line by authorizing extension to other New Jersey communities.

The Port Authority which constructed the line without federal, state or local taxes feels that it has provided a service that has proved itself worthy of federal aid. In 1971, the DRPA began a study to evaluate traffic potential for extended service and to delve into the service factors that might induce more New Jersey suburbanites out of their cars. Study results are expected in mid-1972. The study was bakced by a $750,000 grant from the Urban Mass Transportation Administration and, presumably, will support a later application for UMTA capital and grant funds.

General Findings From Passenger Surveys

While the Philadelphia-Lindenwold system has obviously made its mark on improving suburban rail rapid service, its impact on reducing highway congestion (and air pollution) is less evident and more difficult to measure.

During January-April 1970, PATCO conducted on-board surveys at each of the line's 12 stations. The survey response represented 90 percent of the daily ridership which at that time was 30,000. This survey showed that 40 percent of the riders were former motorists (both drivers and car pool riders). These findings are summarized in Table E-3. It is maintained by PATCO that this diversion level would include traffic on the Ben Franklin and Walt Whitman Bridges.

Table E-3

PRIOR TRAVEL MODE OF PATCO RIDERS
January - April 1970

Former Mode	% of Riders	Est. Distribution of Daily Ridership	Est. Highway Vehicle Trips Not Made
Auto Driver/Rider	40	12,000	10,909[1]
Bus Rider	36	10,800	216[2]
Train Rider	11	3,300	-
Did Not Make Trip	13	3,900	-
Total	100	30,000	11,125

1. Based on car occupancy rates of 1.1 persons.
2. Based on bus capacity of 50 persons.

Source: Former mode by percentage of riders from PATCO 1970 passenger survey.

It is interesting to note that a greater percentage of riders (47 percent) represented former transit riders of bus and train.

Using a vehicle occupancy rate of 1.1 persons per vehicle, it is possible to translate the number of former automobile passengers into motor vehicle trips that are no longer made. Table E-3 shows this diversion to be almost 11,000 trips.[1] Assuming that this vehicular traffic would have traveled on the Benjamin Franklin and Walt Whitman Bridges, these possibly diverted trips represent only 7.6 percent of the average weekday traffic of 143,464 vehicles on both bridges in February 1970. Furthermore, even this small percentage of vehicle diversions is an overestimate because it is based on the assumption that all former auto riders and drivers would have had and used an automobile -- an unlikely situation. Presumably, the vehicle-miles saved would also be a small percentage of the total vehicle-miles traveled.

Bridge Data and Experience

Examination of traffic data for the two Delaware River bridges appears to confirm the diversion of trips to the Lindenwold line (Table E-4). Table E-4 indicates that during 1968-1970, traffic volumes declined by 6 percent on the Benjamin Franklin Bridge and 1 percent on the Walt Whitman. However, no definite cause and effect relationship can be drawn between the rail rapid transit and reduced vehicular volumes on the two Delaware River bridges. To begin with, two major factors operating during this

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[1] As indicated in Table E-3, bus trips account for but a small fraction of the total.

Table E-4

VEHICLE TRAFFIC ON THE WALT WHITMAN AND BENJAMIN FRANKLIN BRIDGES BETWEEN NEW JERSEY AND PHILADELPHIA 1968 through 1970

(millions)

Bridge and Vehicle Category	1968	1969	1970	Percentage Change 1968 - 1970		
				68/69	69/70	68/70
BENJAMIN FRANKLIN BRIDGE						
Automobiles - Regular	12,867	11,813	11,684	-8.2	-1.1	-9.2
Commutation	9,757	10,157	9,663	4.1	-4.9	-0.6
Sub-totals	22,624	21,970	21,347	-2.9	-2.8	-5.6
Buses	851	750	725	-11.1	-4.1	-14.8
Trucks & Misc.	1,129	1,100	1,056	-2.6	-4.0	-6.5
Totals	24,603	23,825	23,129	-3.2	-2.9	-6.0
Average Weekday Volumes	70	68	66	-3.0	-3.3	-5.7
WALT WHITMAN BRIDGE						
Automobiles - Regular	15,955	14,928	15,140	-6.4	1.4	-5.1
Commutation	12,851	13,538	13,385	5.3	-1.1	4.2
Sub-totals	28,806	28,466	28,525	-1.2	0.2	-1.0
Buses	99	81	64	-18.2	-20.9	-35.4
Trucks & Misc.	1,805	1,821	1,827	0.9	0.3	1.2
Totals	30,710	30,368	30,416	-1.1	0.2	-1.0
Average Weekday Volumes	84	83	83	-0.8	0.2	-1.2

Source: Delaware River Port Authority.

period could account for the declines in bridge traffic. First, the Philadelphia-Camden area has experienced extended depressed economic activity which has resulted in reductions in the number of work trips. As indicated earlier, this is particularly true for Camden and has greatly affected Philadelphia to Camden movements. Second, increased bridge tolls in mid-1968 must be considered a strong influence on the decreased bridge usage. This toll increase fell more heavily on individual rides (an increase of 25¢ to 50¢) than on commutation tickets (20¢ to 25¢).

The effect of the bridge toll increases can be seen from the data for both bridges in the shift, between 1968 and 1969, in automobiles from the regular individual toll category to the commutation category. However, automobiles using commutation tickets then declined on both bridges between 1969 and 1970 (4.9 percent on the Franklin Bridge, and 1.1 percent on the Whitman). The toll increases may have also encouraged more car pooling, which would further attenuate the bridge traffic decline such that the decline in vehicular traffic may not represent a similar decline in numbers of people.

The disproportionate declines in bus traffic compared to other vehicles, shown in Table E-4 (i.e., 14.8 percent on the Franklin Bridge and 35.4 percent on the Whitman Bridge), may indicate the lower levels of economic activity, particularly involving low income jobs,[1] as well as the 36 percent diversion of former bus riders to the Lindenwold Line.

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[1] Since generally public transit riders are of lower income levels than automobile commuters.

Figures E-1 and E-2 show hourly traffic volumes for representative months by direction on the Franklin Bridge for the years 1968 and 1970 on a typical week-day -- Wednesday. In the westbound direction on the Franklin Bridge, it was significant that in three out of the four months reviewed, the 1970 traffic peak was higher than the pre-Lindenwold 1968 levels. Since Lindenwold operates on a 24-hour basis some relationship might be considered in slightly lower 1970 values for nighttime and base day volumes. However, the actual differences observed could readily be caused by decreased economic activity.

The eastbound graph shows a lower peak A.M. usage in 1970 for Philadelphia citizens commuting to New Jersey. The P.M. westbound peak traffic to Philadelphia (presumably the reverse flow) also shows a slight decline in two of the four months with the P.M. peak less concentrated, that is spread over a longer time period. Again, depressed economic activity in Camden may have been the reason for these declines.

The impact of the Philadelphia-Lindenwold line on reducing vehicle-miles and air pollution levels is difficult to define. Examination of the bridge traffic data during 1968-1970 does not reveal any significant shifts in overall traffic patterns, other than the declines (already discussed) that would not necessarily be related to the opening of the Lindenwold line. For example, Figure E-3 shows a 12-month moving average for traffic volumes on the two bridges from 1967 through 1971. It is readily apparent that there has been a decline in traffic which pre-dates the opening of the Lindenwold line and is probably related to factors other than the new transit service. The data in Figure E-4 show the annual traffic volumes for the period 1960-70 and confirm that the gradual declines shown in Figure E-3 began before the start of the Lindenwold service. In fact, these traffic declines appear to have started before the increase in toll rates in 1968. This is clearly shown in Table E-5 and Figure E-1 which show the annual percentage change in traffic from 1960 through 1970. The data in Table E-5 and Figure E-1 indicate that in terms of rate of change, traffic on the bridges started to decline between 1966 and 1967. In those years, traffic increased by only 0.3 percent in contrast to the 4-5 percent annual increases for earlier years. This again suggests economic and other forces operating other than the 1968 toll rate increase and the start of the Lindenwold service in 1969.

Table 5

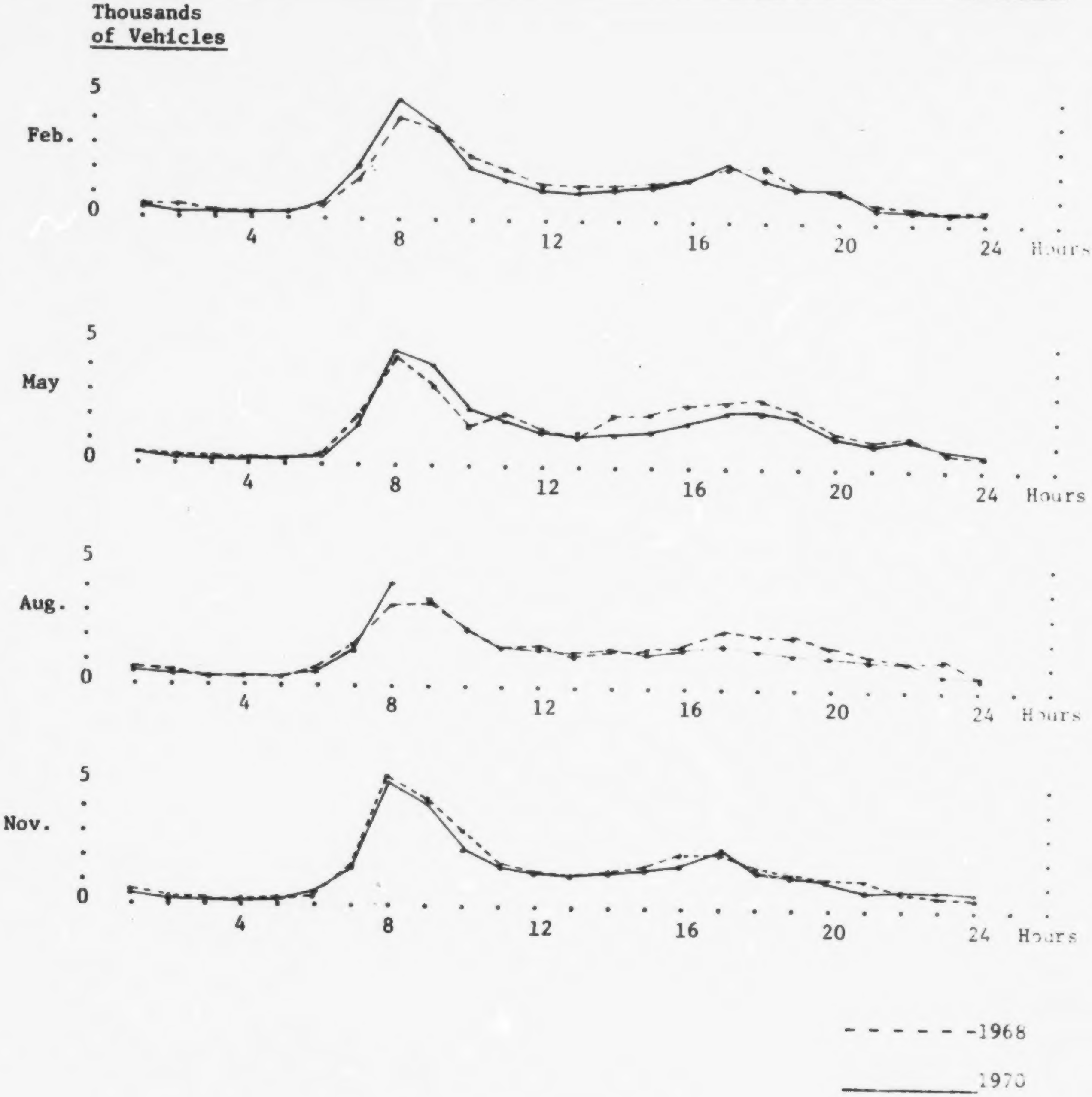
VEHICLE TRAFFIC ON THE WALT WHITMAN AND BENJAMIN FRANKLIN BRIDGES BETWEEN NEW JERSEY AND PHILADELPHIA: ANNUAL VOLUMES AND PERCENTAGE CHANGE 1960-1970

Year	Traffic Volume (thousands)	Percentage Change From Previous Year
1960	43,925	--
1961	44,998	2.4
1962	47,073	4.6
1963	48,254	2.5
1964	50,208	4.0
1965	52,850	5.3
1966	55,483	5.0
1967	55,631	0.3
1968	55,313	-0.6
1969	54,193	-2.0
1970	53,545	-1.2

Source: Delaware River Port Authority

Figure E-1

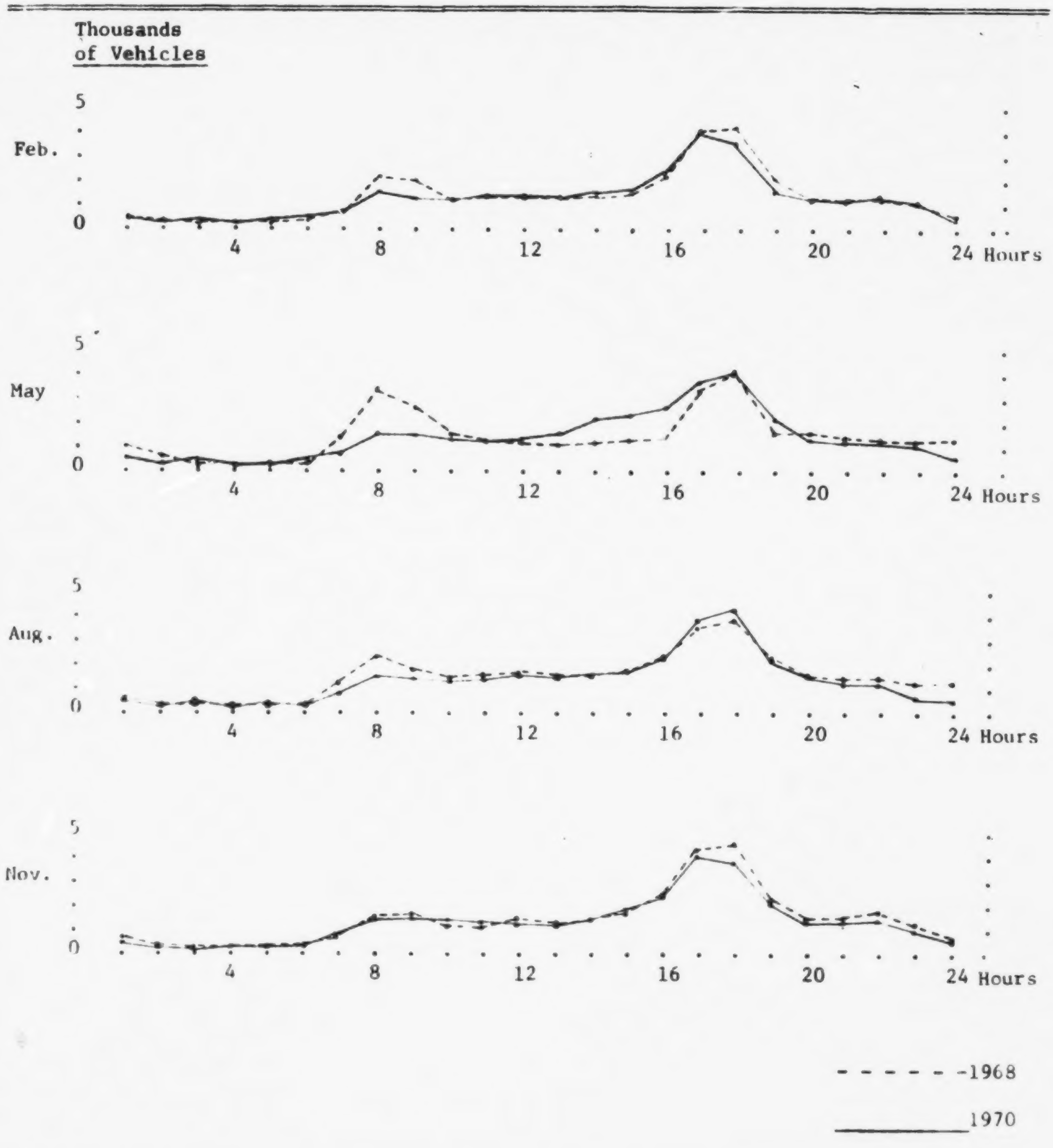
WESTBOUND VEHICLE FLOW ON BENJAMIN FRANKLIN BRIDGE, 1968 and 1970, Hourly Volumes, Average Wednesday, for Selected Months



Source: Delaware River Port Authority

Figure E-2

EASTBOUND VEHICLE FLOW ON BENJAMIN FRANKLIN BRIDGE, 1968 and 1970, Hourly Volumes, Average Wednesday, for Selected Months



Source: Delaware River Port Authority

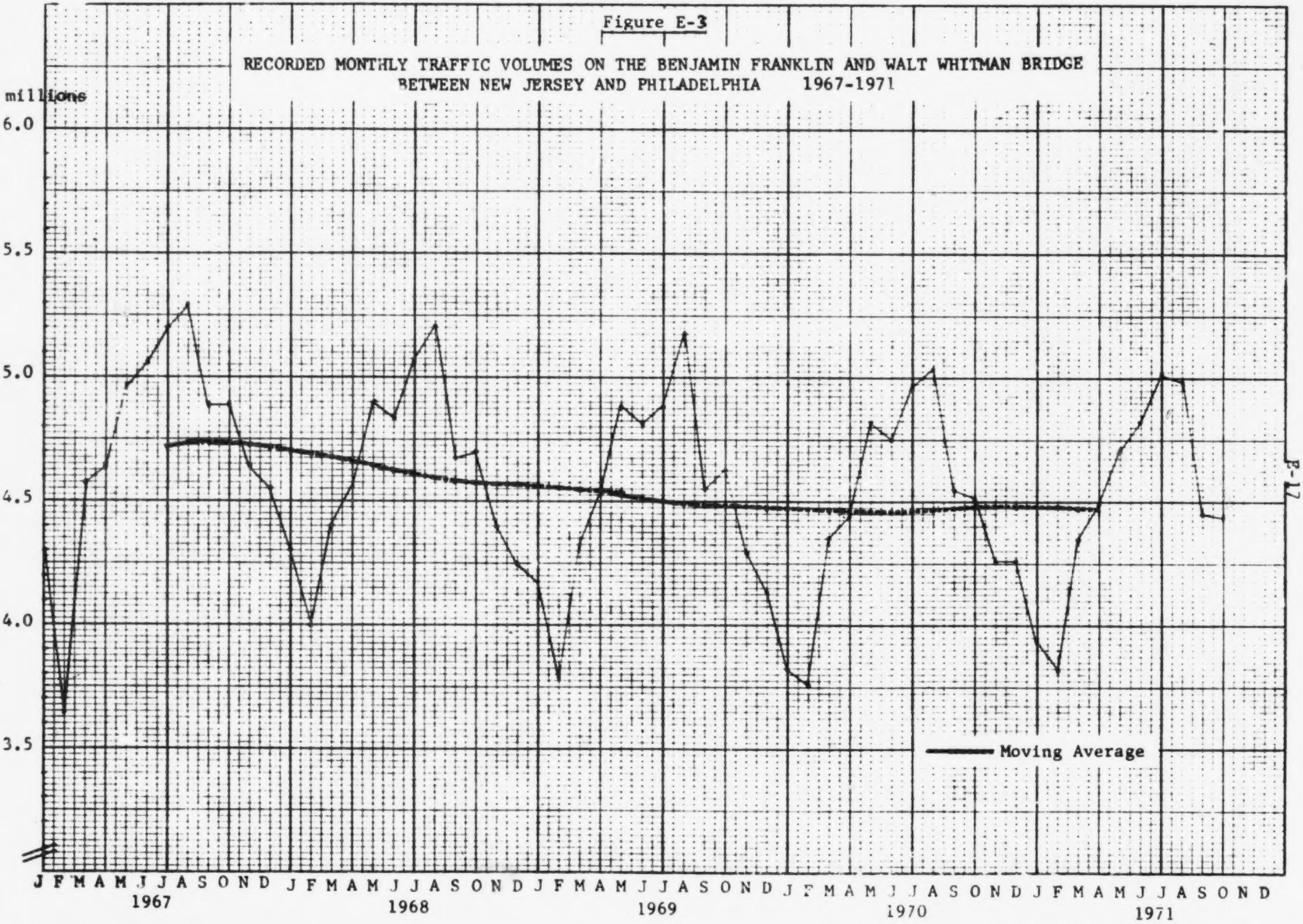


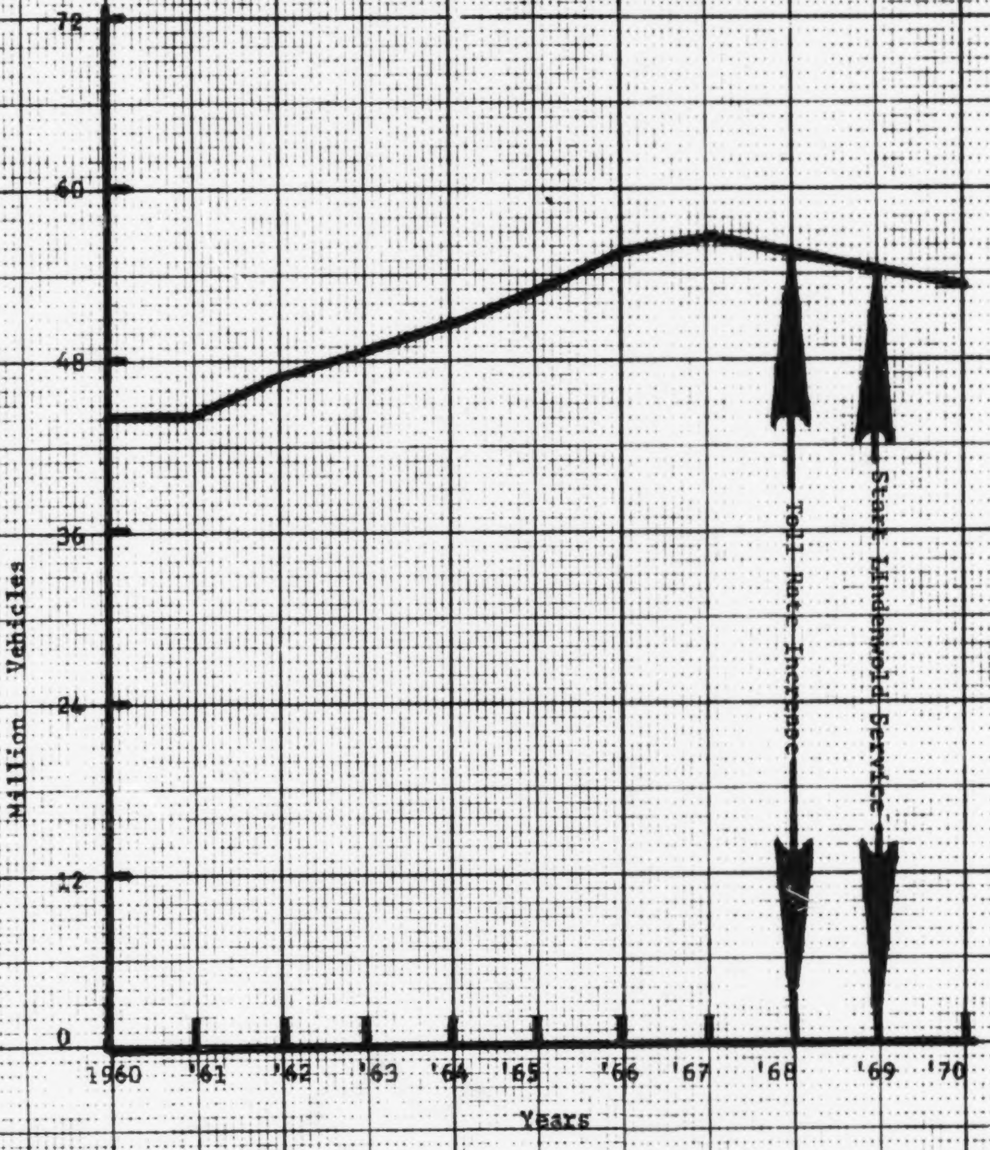
Figure E-3

RECORDED MONTHLY TRAFFIC VOLUMES ON THE BENJAMIN FRANKLIN AND WALT WHITMAN BRIDGE
BETWEEN NEW JERSEY AND PHILADELPHIA 1967-1971

Source: Delaware River Port Authority

Figure E-6

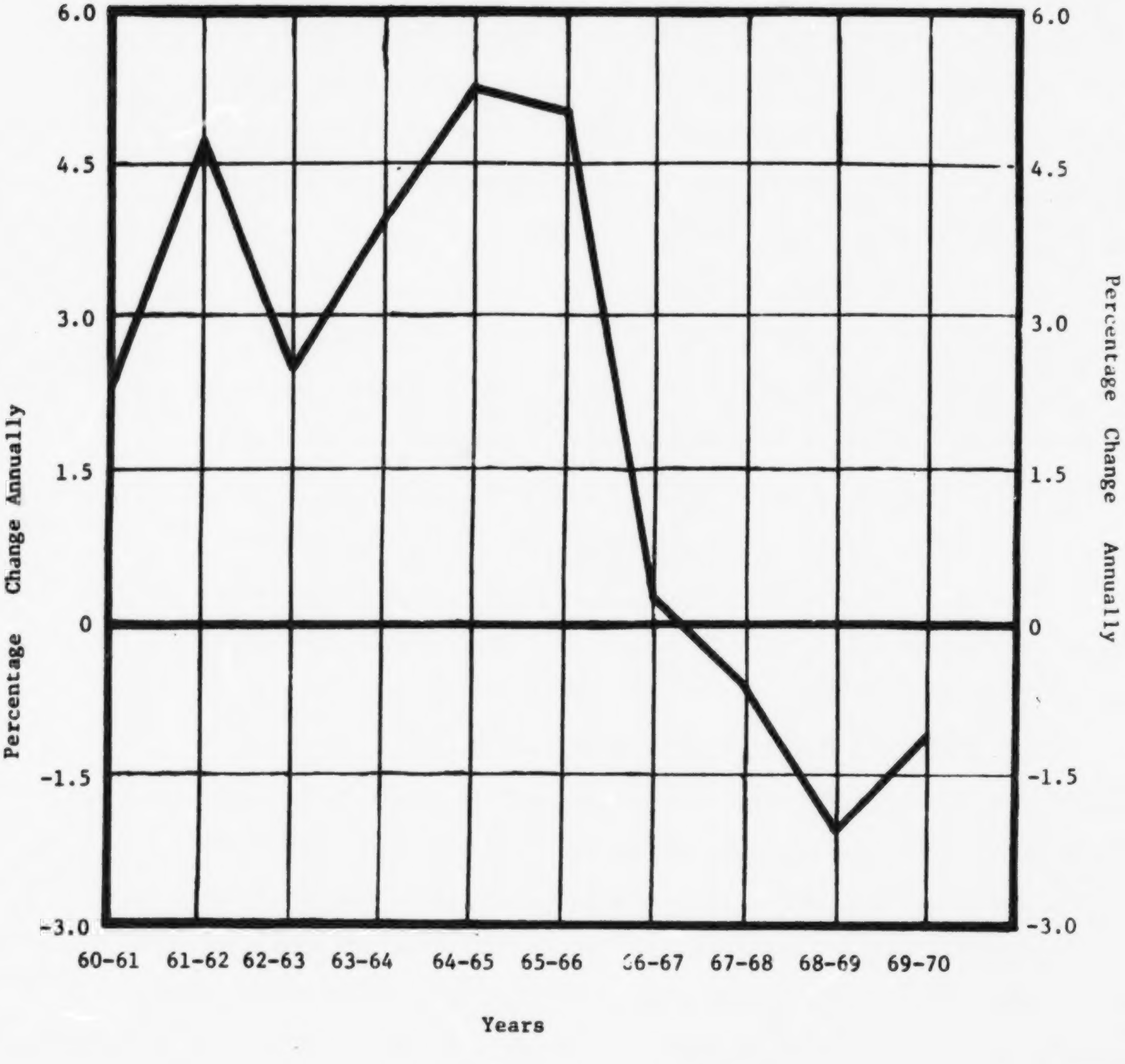
RECORDED ANNUAL TRAFFIC VOLUMES ON THE
BENJAMIN FRANKLIN AND WALT WHITMAN BRIDGES 1960-1970
BETWEEN NEW JERSEY AND PHILADELPHIA



Source: Delaware River Port Authority

Figure E-5

ANNUAL PERCENTAGE CHANGE IN TRAFFIC VOLUMES ON THE WALT WHITMAN AND BENJAMIN FRANKLIN BRIDGES BETWEEN NEW JERSEY & PHILADELPHIA 1960-1970



Source: Delaware River Port Authority

This is not to belittle the value of the service but rather to indicate that a reduction in vehicles directly attributable to the Lindenwold service has not occurred (at least as reflected in the data for the two bridges). Interestingly, bus traffic declined at a much higher rate than other vehicle categories, particularly on the Whitman Bridge which is three miles south of the Lindenwold crossing on the Franklin Bridge. Part of this decline may be related to the fact that a large proportion of riders on the line were diverted from transit buses.

Another consideration of some importance is the fact that the initial diversion from autos does not appear to have continued or increased. Some PATCO officials believe that a 6,000 increase in passengers since the early 1970 daily ridership of 30,000 represents new residents attracted to South New Jersey suburbs by the availability of the Lindenwold Line. Apparent increased real estate activity has been occuring in the areas of the Ashland and Lindenwold stations, and as shown in Table E-2, these two stations are among the three on the Lindenwold Line that have met the forecast ridership.

In summary, the impact of the line on highway traffic and air pollution is difficult to measure because of the unknown effect of increased bridge tolls and general economic depression of the area. The Lindenwold line has also been affected by the area's reduced economic activity in that its projected traffic has not been realized. While the initial 40 percent automobile diversion that appeared on passenger surveys on the rapid transit line remains, this diversion has not grown and appears to be related only to the initial impact of the line. If it were translated into vehicle trips not made or vehicle-miles not driven, the effect on air pollution levels would be negligible.

APPENDIX F

ESTIMATING EMISSION REDUCTIONS FROM MOTOR VEHICLE RESTRAINTS

Elsewhere (Chapter 6 "Maximum Feasible Emission Reduction"), we have offered our best judgments about the reduction in motor vehicle traffic which might result from higher parking rates[1] (as much as quadrupled) in Washington, D. C. In this appendix we review the evidence upon which these judgments are based and indicate some of the difficulties in drawing conclusions from existing data and modal split analyses. In the following discussion of motor vehicle restraints we assume that public transport will be importantly improved in order to serve as a substitute for motor vehicle trips. Without these improvements, diverted motorists will be unlikely to use public transport, and access for work and other trip purposes would be seriously constrained, with profound social and economic consequences.

The emission reduction potential of motor vehicle restraints is a function of the severity of those restraints. Obviously, if the number of parking spaces were significantly reduced in downtown areas, motor vehicle miles traveled into and around these areas (and resulting emissions) could be significantly reduced. Conversion of major portions of any central city into vehicle-free zones could have an even more dramatic effect. However, complete bans on motor vehicle use in major portions of any metropolitan area are clearly not feasible by 1977. In addition to the practical problems (e.g., providing alternative transportation) the political opposition (e.g., from automobile owners' associations, downtown merchants) would be enormous. Furthermore, it is difficult at this time to see where strong political support for such complete exclusion would come from.

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[1] Controls over parking may be considered as a "surrogate variable" for motor vehicle restraints.

Assuming a more modest program of motor vehicle restraints, however, what emission reductions might be reasonably expected? Unfortunately, present knowledge does not permit a definite answer. No systematic study has been made of the price elasticity of motor vehicle use,[1] although there are some indicative observations. For instance, parking prices set at market rates have risen steadily the past two decades in cities such as Washington, D. C. During this time, traffic in Washington, D.C. has also increased steadily and more parking spaces have become available (as parking continues to be a profitable business). Monthly parking contracts in densely developed areas of the District of Columbia are now up to $30 to $35 on open lots and $40 to $45 in office buildings. In effect, the daily rate is between $1.50 and $2.00. The so-called "daily rates" range between $2.00 and $3.00 for the same areas. At present, no systematic price change -- motorist response data are available for parking charges, but at the gradual rate prices have risen, it is clear that there has been no reduction in traffic.[1]

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[1] Price elasticity here refers to the percentage change in motor vehicle use accompanying a change in the cost of using the motor vehicle (either investment, operating or time cost).

The World Bank, which is also strongly interested in such matters, has recently published a study of road pricing which develops some elasticity data for use in congestion pricing plans.[2] The data presented were derived from observations made by the Road Research Laboratory in the United Kingdom, mostly in the London area. Interpretation of these data indicates that imposing road pricing rates of 10¢ to 20¢ per vehicle-mile would reduce traffic volumes by 20 to 30 percent.[3] The resulting road pricing costs for typical commuting trips in the London area are shown in Table F-1.

For a number of reasons, however, the United States response to such increases would be much less than that for England. In our judgment, the rate of 20¢ per mile (which for the average trip in Washington, D.C. would be about $4.00 or a total charge of $88.00 a month) would have a

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1. However, incomes have also been on the rise so that "real" increases in parking rates may be much lower than they seem.

While attempting to determine the price elasticity of motor vehicle use, we contacted the International Bridge, Tunnel and Turnpike Association. None of the Association's members had made specific elasticity studies. They are strongly disposed not to reduce toll rates, and in some cases have doubled them. They uniformly report that there was an immediate drop in traffic volume,which recovered in six months or less, at which time previous traffic road rates were resumed.

2. See A. A. Walters, The Economics of Road User Charges, International Bank for Reconstruction and Development, Occasional Paper No. 5: 1968. Unfortunately, for purposes here, the basic objective of this study (to examine revenue raising measures by road pricing of congested traffic for purposes of building additional road capacity) was significantly different from that of air pollution control.

3. Ibid., pp. 178, 200.

Table F-1

ROAD PRICING RATES FOR TYPICAL COMMUTING TRIPS IN LONDON AREA

Length of Commuter Trip	Total Cost at Different Rates[1]	
	10¢/mi.	20¢/mi.
4	$ .80	$1.60
6	1.20	2.40
10	2.00	4.00
15	3.00	6.00

Source: A. A. Walters, The Economics of Road User Charges, International Bank for Reconstruction and Development, Occasional Paper No. 5, 1968.

1. Two-way round trip miles; all costs converted to U.S. dollars.

maximum diversion effect of 15 to 20 percent, and would have to be accompanied by important public transport improvements in order to be implementable. This type of charge is of some interest because the price is adjusted to trip length, whereas a proposed parking charge would be a flat rate (irrespective of trip length) and would therefore be regressive on those using cars for relatively short distances. From a transportation point of view, this does not seem objectionable, as it could be assumed that short distances may be more easily made on public transport.[1] At least in areas such as Los Angeles and Washington, D. C., it can also be argued that drivers coming the longest distances are usually the most poorly served by public transport. This would not be true where well developed commuter railroads are in operation (e.g., New York City, Chicago, Philadelphia).

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[1] From an air pollution control point of view, however, it may be desirable to discourage long trips.

Another possible source of elasticity data are the modal split models used by transportation planners. Setting aside details of methodology, the major purpose of modal split analysis is to estimate the proportion of person trips that will be made by a public transport and the private automobile.[1] A number of variables are examined related to one another in order to measure the impact of changes in these variables on transit ridership. In general, key variables include income, vehicle operating costs, time differentials between transit and motor vehicles, vehicle ownership, vehicle occupancy and parking costs.

Using the total trip estimates projected from comprehensive transportation studies (usually available for major metropolitan areas) person trips are apportioned among modes. Typically, however, the modal split models do not indicate whether diversions to transit will result in reduced motor vehicle use. For example, a modal split model may indicate that with the construction of a new rapid transit system, approximately 15 percent of total trips would travel on the new system. Assuming that 15 percent represented about 10 000 trips diverted into transit, there is usually no indication what would happen to motor vehicle use (i.e., will it increase, decrease or remain the same).

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1. The analysis is usually for a 25 hour period as well as for peak hours (a.m. and p.m.) for all trip purposes.

Increased transit trips may not necessarily reduce motor vehicle use for several reasons. For one thing, part of the ridership may come from present bus riders, who divert to a more convenient transit. Another part of the ridership may come from motor vehicle riders (distinct from drivers) who are in a car pool and find the transit less costly and equally or more convenient (there is some evidence that vehicle occupancy rates decline with improved transit). Finally, some trip makers (perhaps presently on transit) may become automobile drivers (i.e., enter into the traffic stream) as they discover that congestion has been reduced somewhat. And, in the medium and long term, assuming auto traffic continues to grow, the level of traffic will return and eventually surpass what levels had been prior to implementation of the new transit system.

By no means is it suggested that there will be no reduction of motor vehicle use associated with public transport improvements. However, these reductions will probably be offset by the forces just described although there is little available data which permit a definitive evaluation of the net change. In one case where data are available (i.e., for the Bay Area Rapid Transit [BART] system in the San Francisco area), estimates have been made of the reductions in motor vehicle use for 1975 projected traffic, both in terms of vehicle miles traveled and trips. These estimates of the impact of BART indicate that "in the four counties of Alameda, Cortra Costa, San Francisco and San Mateo, the trips diverted from motor vehicles to BART by 1975 will reduce the vehicle miles of travel per day by 2.1 percent."[1] Similar estimates for the San Francisco and East Bay areas indicate that by 1975 there would be reductions of 3.1 and 1.5 percent respectively.[2] Estimates were also made for the San Francisco-Oakland Bay Bridge, and even along this important line-haul corridor where transit is most competitive, "the person trips diverted from motor vehicles using the Bay Bridge to BART would represent a reduction in total vehicle miles per day of 8.1 percent by the year 1975."[3]

Another case in point concerning modal split procedure relates to the model developed in the 1960's for application to Washington, D. C. In the course of developing the model, an attempt was made to assess the sensitivity of the procedure (i.e., its ability to reflect changes in input variables). One sensitivity test involved doubling parking costs in the zero sector zones (which approximate the downtown CBD) of Washington, D.C. Results from this test are shown in Table F-2.

Unfortunately, there is very little empirical data on which to establish the cause and effect relationships among the variables used in this (or any other modal split) model. In many cases, the models merely reflect

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[1] California Air Resources Board, "Air Quality Control Plan" (preliminary draft, November 15, 1971), p. 15. In connection with this estimate, it should be noted that the BART system only includes the four counties above.

[2] Ibid., especially see chapter on "Impact of Mass Transit."

[3] Ibid., p. 12.

Table F-2

SENSITIVITY OF WASHINGTON, D. C. MODAL SPLIT MODEL TO DOUBLING PARKING PRICES IN DOWNTOWN OF WASHINGTON, D. C.

	Base[1]	Doubled Parking Costs
Total person trips	465,825	465,825
Number via transit	108,169	115,972
Percent diversion	0.2322	0.2490
Percent change	---	+7.2
Person trips to CBD	148,390	148,390
Number via transit	85,952	92,609
Percent diversion	0.5794	0.6241
Percent change	---	+7.7
Non-CBD oriented person trips	317,435	317,435
Number via transit	22,217	---
Percent diversion	0.0700	0.0700
Percent change	---	---

Source: Arthur B. Sosslau, Kevin E. Heanue, and Arthur J. Balek, "Evaluation of a New Modal Split Procedure," (paper prepared by the Federal Highway Administration for the Highway Research Board Committee on Origin and Destination).

1. National Capital Transportation Agency traffic assignment model, using 1955 origin and destination data, a.m. peak traffic hours, working trips only.

the working assumptions of transportation analysts, and cause and effect relationships are imperfectly understood. As a result, modal split models are useful only within narrow ranges and are heavily weighted upon past experience. They do not help when major policy variables are being altered (e.g., a significant reduction in motor vehicles entering the CBD).

Limitation of the modal split model to relationships within relatively narrow ranges was noted in the following caution taken from the above-cited article prepared by the Federal Highway Administration for the Highway Research Board:

> The modal split procedure was sensitive to changes in the cost ratio only in a very limited range. From the drastic changes in the cost ratio variable -- double transit figures to double parking costs -- the number of estimated riders ranged from only 99,752 to 115,972.[1]

Another source of modal split data can be found in an analysis of the Minneapolis-St. Paul area in the late 1950's. The parking cost variable used in the modal split analysis tends to confirm the inelasticity suggested above with regard to the Washington, D. C. model. Based on a 1958 survey of origins and destinations and parking, the model related parking costs per hour to transit usage in the two CBDs.[2] The relationship is shown in Figure F-1. The average amounts actually spent were also calculated for 3-hour and 9-hour parking periods. The CBD averages were 5-10¢ for a three-hour period (about 40¢-80¢ for an 8-hour day) and slightly less for a 9-hour period. The average per hour cost in 1958 has also been shown in Figure F-1.

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[1] Arthur B. Sosslau, Kevin E. Heanue, and Arthur J. Balek, "Evaluation of a New Modal Split Procedure," (paper prepared by the Federal Highway Administration for the Highway Research Board Committee on Origin and Destination). This is not to suggest an error, but rather that demand is relatively inelastic.

[2] U.S. Department of Commerce, Bureau of Public Roads, Office of Planning, Modal Split, Documentation of Nine Methods for Estimating Transit Usage (Washington, D.C.: Government Printing Office, 1966), see especially pp. 96 and 100.

At the 1958 average level of parking cost, transit usage was in the range of about 30 percent. If parking prices were doubled (to 80¢-$1.60 a day), and the functional relationship in Figure F-1 is correct, transit usage would have risen to about 45 percent -- a relatively small increase, when measured against the number of motor vehicle trips which might have been reduced. Furthermore, as already noted, many of these trips would not result in a 1:1 reduction in motor vehicle use. It would also appear from Figure F-1 that achieving 80 percent transit usage in Minneapolis-St. Paul in 1958 would have required quadrupling parking prices.

A modal split model for the planning of the Baltimore Rapid Transit System included a feature not typically found in modal split models, namely the testing of different levels of parking charges in the model.[1] The parking charges tested ranged from 4¢ per hour (approximately 30 to 35¢ a day) to 30¢ per hour (approximately $2.50 to $3.00 per day). These rates were applied to three categories of trips, and the curves were produced by the model for the full range of travel time ratios (i.e., the difference between the door-to-door time for motor vehicles in transit).

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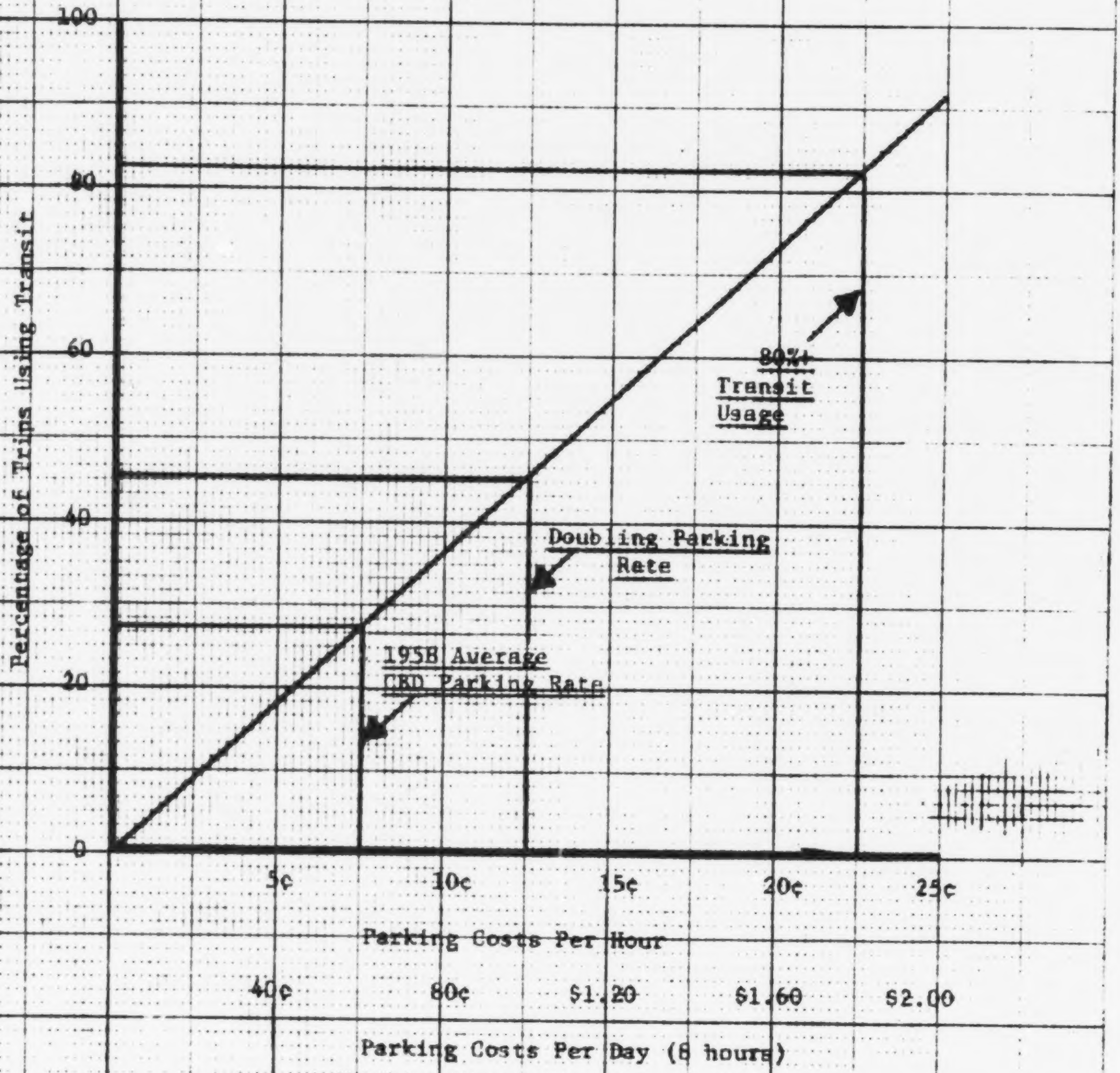
[1] See Alan M. Voorhees & Associates, Inc., A Report on Mode Choice Analysis for the Baltimore Region, AMV-R-20-1043(921) (McLean, Va.: Alan M. Voorhees & Associates, Inc., undated).

Figure F-1



PARKING COST AND PERCENTAGE OF TRIPS BY TRANSIT
MINNEAPOLIS-ST. PAUL 1958

Source: Adapted from U.S. Department of Commerce, Bureau of Public Roads, Office of Planning, *Modal Split, Documentation of Nine Methods for Estimating Transit Usage* (Washington, D.C.: Government Printing Office, 1966), pp. 96 and 100.

Six income levels were used from "under $2,500 per annum" to "over $10,000 per annum." (See Table F-3 and Figure F-2)

Unfortunately, the resulting groups of curves are not uniform and do not lend themselves to averaging. For trips between house and work where transit and auto travel times are the same (no difference implies a relatively high quality of transit service), the curves indicate that after the transit fare rises above 75 percent of the market, the demand for auto travel is relatively inelastic at nearly all income levels. In other words, it is extremely difficult to shift further motor vehicle users to transit. The curves also indicate that in Baltimore the low income groups already have relatively high transit ridership, so that, for these income groups, the amount of shifting would be negligible. Contrariwise, the highest income group offers greatest diversion potential. It should be stressed, however, that the proposal transit system in the Baltimore model is a high quality six-line rapid rail system which would require 15 years to complete.

For reasons not entirely clear, the Baltimore modal split model shows the greatest elasticity for the first increment of change in parking prices, from 0 to 4¢ and 5 to 8¢ per hour at all income levels but especially for higher income groups above $5,000 per annum. This "result" has not been satisfactorily explained, and is apparently an abberation of this particular model. This model did forecast that with a daily parking cost of $2.50 or higher, all income groups receiving good transit service (with no travel time differential) would have transit ridership above 50 percent, ranging from 84 percent for the lowest income groups down to 53 percent for the highest. (See Figure F-2.)

Table F-3

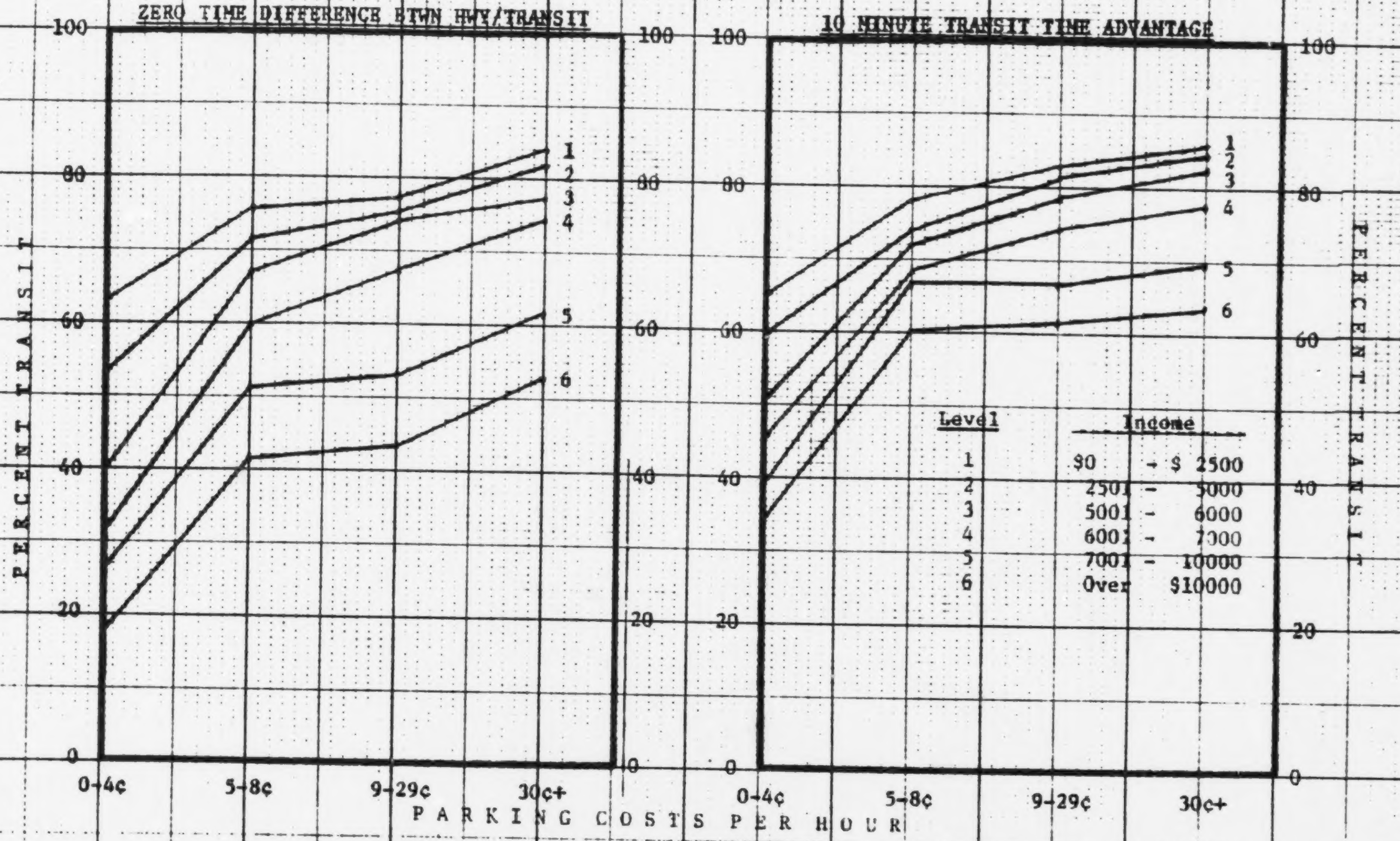
MODE CHOICE ANALYSIS FOR BALTIMORE - PERCENT TRANSIT TRIPS FOR VARIOUS PARKING RATES WORK TRIPS

	Income Group	Percent Transit Usage at Parking Rate 0-4¢/hr.	5-8¢/hr.	9-29¢/hr.	30¢+/hr.
		Zero Time Differential Between Highway and Transit			
1.	$0-$2,500	64%	76%	78%	84%
2.	$2,501-$5,000	54	72	76	82
3.	$4,001-$6,000	40	68	75	78
4.	$6,001-$7,000	32	60	68	75
5.	$7,001 $10,000	27	52	54	62
6.	Over $10,000	18	42	44	53
		10 Minute Time Advantage to Transit			
1.	$0-$2,500	66	78	83	86
2.	$2,501-$5,000	59	74	82	85
3.	$5,001-$6,000	50	72	79	83
4.	$6,001-$7,000	44	68	75	78
5.	$7,001-$10,000	38	66	68	70
6.	Over $10,000	33	60	62	64

Source: Alan M. Voorhees & Associates, Inc., A Report on Mode Choice Analysis for the Baltimore Region, AMV-R-20-1043(921) (McLean, Va.: Alan M. Voorhees & Associates, Inc., undated), Fig. 3-3 through 3-6, pp. 20-23.

Figure F-2

MODE CHOICE ANALYSIS FOR BALTIMORE-PERCENT TRANSIT TRIPS FOR VARIOUS PARKING RATES-WORK TRIPS



Source: Alan M. Voorhees & Associates, Inc., A Report on Mode Choice Analysis for the Baltimore Region, AMV-R-20-1043(921) (McLean, Va.: Alan M. Voorhees & Associates, Inc., undated), Fig. 3-3 through 3-6, pp. 20-23.

At the time of the forecast, $2.50 per day was higher than the average downtown Baltimore parking rate. Table F-2 shows what an increase in parking costs from 60¢ to $2.50 per day (assuming the relationship shown in Table F-3 and Figure F-2 is correct) would produce for Baltimorians for whom there are no travel time differences between motor vehicles and transit (i.e., excellent transit service) and with a 10-minute time advantage to the auto. The column showing percentage change in transit ridership (last column in Table F-4) clearly illustrates the sensitivity of the upper income groups to changes in the price of parking and the influence of trip times.

Examination of these and other curves from the Baltimore modal split study indicates that in the corridors where relatively good transit service (i.e., frequent schedules and/or express bus lines) is already in operation, there will be relatively small diversions from autos to transit, even with a quadrupling of parking costs. On the other hand, these data indicate that with a substantial improvement in transit travel time and a quadrupling in parking costs, relatively large diversions could be obtained from the upper income groups of drivers. Unfortunately, there is no way to weight the Baltimore income groups to develop an "average." It must also be pointed out that the Baltimore curves assume a large rapid transit system. In most cities without rapid rail, only close-in residents living near major arterials with multiple bus lines could ever receive bus transit service that would provide the same elapsed time as driving.

In sum, the major problem with relying heavily on relationships provided by calculations with modal split models is that they are

Table F-4

SENSITIVITY OF BALTIMORE, MD., MODAL SPLIT MODEL TO CHANGES IN PARKING PRICES

	Income Group	Percent of Home-Work Riders on Transit[1]			
		60¢/day	$2.50/day	Diff.% points	% Incr.
1.	$0-$2,500 p.a.	76%	84%	8	11
2.	$2,501-$5,000	72	82	10	14
3.	$5,001-$6,000	68	78	10	15
4.	$6,001-$7,000	60	75	15	25
5.	$7,001-$10,000	52	62	10	19
6.	$10,000 and over	42	53	11	26
		Percent of Home-Work Riders on Transit[2]			
1.	$0-$2,500 p.a.	72	78	6	8
2.	$2,501-$5,000	67	75	8	12
3.	$5,001-$6,000	61	74	13	21
4.	$6,001-$7,000	50	70	20	40
5.	$7,001-$10,000	38	56	18	47
6.	$10,000 and over	28	46	18	64

Source: Alan M. Voorhees & Associates, Inc., A Report on Mode Choice Analysis for the Baltimore Region, AMV-R-20-1043(921) (McLean, Va.: Alan M. Voorhees & Associates, Inc., undated).

1. Assumes no travel time differential between motor vehicle and transit.

2. Assumes 10 percent travel time differential in favor of motor vehicles.

based upon limited data for determining driver reactions to cost differential factors. Many assumptions (amounting to judgment) have been used as inputs for the models. While the Baltimore model provides data which are encouraging from an air pollution control standpoint, it is calibrated to a compact industrial city with very good bus transit service in the past and relatively low incomes. The direct application of these untested modal split model-derived ratios must be approached with considerable caution.

Nevertheless, on the basis of available evidence our best judgment is that improvements in public transport which are feasible within five years (i.e., by 1977) will not by themselves reduce motor vehicle traffic by more than 5 percent. Furthermore, there is no evidence to indicate that any permanent reduction in traffic would be possible without motor vehicle restraints.

The response to changes in parking rates (taken here as a surrogate for motor vehicle restraints) is likely to differ depending on whether motorists have free or subsidized parking or whether they already pay the going rate. Evidence suggests that for those paying the full rate, doubling parking rates in the CBD (say, from $30 to $40 per month in the core of Washington, D. C. to $60 or $80) would have a minor effect, perhaps not to exceed a 5 percent reduction in motor vehicle traffic. For the market which now pays the current rates, most of the marginal users have already been "squeezed out."

If higher parking rates[1] were imposed (presumably through taxes) on employees receiving full parking space or on the employers now furnishing it, a reduction by 15 to 20 percent in motor vehicle traffic might be possible. There are undoubtedly a great many more marginal drivers among those in free parking spaces than among those in already costly space. This consideration also implies that in any strategy to control parking, the first effort should be to eliminate all free spaces and to greatly increase the charge for meter parking, at least to 25¢ per hour.

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[1] Say, an "overnight" increase from $0.00 to $60 to $80 per month for all workers parking in the CBD.

Evidence from the Baltimore modal split analysis suggests that the middle to high income suburbanite commuters are likely to be the most responsive to changes in the parking rates, if good public transport is available for the work trip. Vehicle occupancy is also likely to rise (which in itself would tend to reduce vehicle miles traveled).

Finally, if under a comprehensive parking control program, a parking space tax of $60 to $80 for all spaces were applied in the CBD of Washington, D.C. (and comparable rates in other cities), and if all on-street parking were eliminated (including most of the illegal parking) there might be an overall reduction in motor vehicle traffic of perhaps 20 percent or at the most 25 percent. Again, all this assumes that public transport would be importantly improved to provide an alternate means of making trips. Such a comprehensive parking control program for Washington, D.C. would imply a tripling or quadrupling of existing rates to $90 to $120 per month for existing pay parking and $60 to $80 for existing free parking. These levels would appear to be the upper limit of practical action at present.

G-1

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